

NOTICE OF PROPOSED RULEMAKING TECHNICAL SUPPORT DOCUMENT ENERGY CONSERVATION PROGRAM FOR CONSUMER PRODUCTS AND CERTAIN COMMERCIAL AND INDUSTRIAL EQUIPMENT:

**GENERAL SERVICE FLUORESCENT LAMPS AND
INCANDESCENT REFLECTOR LAMPS**

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CHAPTER 1. INTRODUCTION

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CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a stand-alone report that provides the technical analyses supporting the information in the notice of proposed rulemaking (NOPR) for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs).

1.2 OVERVIEW OF THE APPLIANCES AND COMMERCIAL EQUIPMENT STANDARDS PROGRAM

Title III of the Energy Policy and Conservation Act of 1975 (EPCA; 42 U.S.C. 6291–6317), as amended, established the “Energy Conservation Program for Consumer Products Other Than Automobiles,” which includes major household appliances.^a Additional amendments to EPCA have given the U.S. Department of Energy (DOE) the authority to regulate the energy efficiency of several products, including certain GSFLs and IRLs, products which are the focus of this rulemaking.

DOE designs any new or amended standard to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) To determine whether a standard is economically justified, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the following seven factors:

- (1) the economic impact of the standard on the manufacturers and consumers of the products subject to the standard;
- (2) the savings in operating costs throughout the estimated average life of the products compared to any increases in the price, initial charges, or maintenance expenses for the products that are likely to result from the imposition of the standard;
- (3) the total projected amount of energy savings likely to result directly from imposition of the standard;
- (4) any lessening of the utility or the performance of the products likely to result from imposition of the standard;
- (5) the impact of any lessening of competition, as determined in writing by the Attorney General, likely to result from imposition of the standard;
- (6) the need for national energy conservation; and

^a Part B was re-designated Part A on codification in the U.S. Code for editorial reasons.

(7) other factors the Secretary considers relevant.

(42 U.S.C. 6295(o)(2)(B)(i))

1.3 OVERVIEW OF GSFL AND IRL STANDARDS

Amendments to EPCA in the Energy Policy Act of 1992 (EPAc 1992), P.L. 102-486, established energy conservation standards for certain classes of GSFLs and IRLs, and authorized DOE to conduct two rulemaking cycles to determine whether these standards should be amended. (42 U.S.C. 6291(1), and 6295(i)(1) and (3)-(4)) EPCA also authorized DOE to adopt standards for additional GSFLs, if such standards were warranted. (42 U.S.C. 6295(i)(5)) DOE completed the first cycle of amendments by publishing a final rule in July 2009 (hereafter the “2009 Lamps Rule”). 74 FR 34080 (July 14, 2009). The 2009 Lamps Rule addressed two statutory directives under 42 U.S.C. 6295(i) by amending existing energy conservation standards for GSFLs and IRLs (42 U.S.C. 6295(i)(3)) and adopting standards for additional GSFLs (42 U.S.C. 6295(i)(5)). That rule also amended the definition of “colored fluorescent lamp” and “rated wattage” and adopted test procedures applicable to the newly covered GSFLs.^b

This rulemaking is DOE’s second cycle of review to determine whether the standards in effect for GSFLs and IRLs should be amended and whether the standards should apply to additional GSFL types as directed by EPCA. (42 U.S.C. 6295(i)(3)-(4) and (5)) DOE developed the analytical framework in the “Energy Conservation Standards Rulemaking Framework Document for General Service Fluorescent Lamps and Incandescent Reflector Lamps” (August 31, 2011).^c DOE presented this analytical approach to interested parties during a public meeting held on October 4, 2011 (hereafter the “framework public meeting”).

DOE issued the preliminary analysis for this rulemaking on February 20, 2013 and published it in the *Federal Register* on February 28, 2013. 78 FR 13563. DOE posted the preliminary analysis, as well as the complete preliminary TSD, on its website.^d The preliminary TSD includes the results of the following DOE preliminary analyses: (1) market and technology assessment; (2) screening analysis; (3) engineering analysis; (4) energy use characterization; (5) product price determinations; (6) LCC and PBP analyses; (7) shipments analysis; and (8) national impact analysis (NIA). DOE presented its methodology and results from the preliminary analysis to interested parties during a public meeting held on April 9, 2013 (hereafter the “preliminary public meeting”).

^b Information regarding the 2009 Lamps Rule can be found on regulations.gov, docket number EERE-2006-STD-0131 at www.regulations.gov/#!docketDetail;D=EERE-2006-STD-0131.

^c The framework document is available on regulations.gov, docket number EERE-2011-BT-STD-0006, at www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0002.

^d The preliminary analysis, preliminary TSD, and preliminary analysis public meeting information are available at http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24.

This rulemaking also addresses 42 U.S.C. 6295(gg)(3), in which DOE is directed to incorporate standby mode and off mode energy use in any new or amended standard adopted after July 1, 2010 pursuant to 42 U.S.C. 6295(o). Please see chapter 2 of this NOPR TSD for a detailed discussion of DOE's consideration of standby and off mode energy consumption.

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

DOE considers stakeholder participation a very important part of the standards-setting process. DOE encourages the participation of all stakeholders during the comment period of each rulemaking stage. Beginning with the rulemaking framework document for GSFLs and IRLs (hereafter the "framework document") and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for the standards rulemaking.

In conducting test procedure and the energy conservation standard rulemakings, DOE involves interested parties through formal public notifications (*i.e.*, *Federal Register* notices). For this GSFL and IRL energy conservation standards rulemaking, DOE will employ the procedures set forth in DOE's Process Rule ("Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products," 61 FR 36974 (July 15, 1996), 10 CFR Part 430, Subpart C, Appendix A) to the extent they are appropriate for developing energy conservation standards for the lamps covered under this rulemaking.

Before DOE determines whether to amend energy conservation standards for GSFLs and IRLs, it must first solicit comments on a proposed standard. (42 U.S.C. 6295(o)(2)(B)(i)) DOE must design new standards for these products to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified, and would result in significant energy savings. (42 U.S.C. 6295(o)(2)(A) and (3)) To determine whether a proposed standard complies with these requirements, DOE must, after receiving comments on the proposed standard, determine whether the benefits of the standard exceed its burdens to the greatest extent practicable, weighing the seven factors described in section 1.3.

Subsequent to the publication of the framework document, the standards rulemaking process involves preliminary analyses followed by two additional formal, major public notices, which are published in the *Federal Register*. The preliminary analyses are designed to publicly vet the models and tools used in the rulemaking and to facilitate public participation before the proposed rule stage. After the preliminary analyses are vetted, DOE issues the first major notice, the NOPR, which presents a discussion of comments received in response to the preliminary analyses of the impacts of standards on consumers, manufacturers, and the nation; DOE's weighing of the impacts; and the proposed standards. The second notice is the final rule, which presents a discussion of comments received in response to the NOPR; the revised analysis of the impacts of standards; DOE's weighing of the impacts; the standards adopted by DOE; and the compliance dates of the standards.

Table 1.4.1 Analyses under the Process Rule

Preliminary Analysis	NOPR	Final Rule*
Market and technology assessment	Revised preliminary analyses	Revised analyses
Screening analysis	Life-cycle cost sub-group analysis	
Engineering analysis	Manufacturer impact analysis	
Energy use characterization	Emissions analysis	
Product price determination	Monetizing of emissions reductions benefits	
Life-cycle cost and payback period analysis	Utility impact analysis	
Shipments analysis	Employment impact analysis	
National impact analysis	Regulatory impact analysis	
Preliminary manufacturer impact analysis		

* During the final rule phase, DOE considers the comments submitted by the U.S. Department of Justice concerning the impact of any lessening of competition that is likely to result from the imposition of the standard. (42 U.S.C. 6295(o)(2)(B)(v))

As previously mentioned, on September 14, 2011, DOE published a notice announcing the availability of the framework document and a public meeting to discuss the proposed analytical framework for the rulemaking. 76 FR 56678. The framework document and public meeting information are available at regulations.gov under docket number EERE-2011-BT-STD-0006. Links to these documents can also be found on DOE's website:

www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24.

DOE held the public meeting on October 4, 2011 to discuss procedural and analytical approaches to the rulemaking and to inform and facilitate stakeholders' involvement in the rulemaking process. The analytical framework presented at the public meeting described rulemaking analyses, such as the engineering analysis and the LCC and PBP analysis, the methods proposed for conducting them, and the relationships among the various analyses. See Table 1.4.1 for all the analyses discussed at the public meeting and the stage at which the analyses are undertaken. PDF copies of the slides and other material associated with the public meeting are available at:

www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24.

During the framework public meeting and the framework document comment period,^e stakeholders, including manufacturers, trade associations, environmental advocates, and other interested parties submitted several comments about the GSFL and IRL rulemaking. The major issues discussed were: scope of coverage, metrics, product classes, efficacy level approach, shipment trends, rare earth materials, and the unknown impacts of the 2009 Lamps Rule. A

^e The National Electrical Manufacturers Association (NEMA) requested that DOE extend the comment deadline from the original October 31, 2011 to November 28, 2011. DOE agreed and moved the comment deadline accordingly. The notice extending the framework comment period is available on regulations.gov, docket number EERE-2011-BT-STD-0006, at www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0011.

detailed discussion of stakeholder comments is available in chapter 2 of the preliminary analysis TSD.

As part of the information gathering and sharing process, DOE organized and held interviews with GSFL and IRL manufacturers who operate in the U.S. market. DOE had five objectives for these interviews: (1) solicit feedback on the scope of coverage for the rulemaking; (2) solicit feedback on the engineering analysis; (3) solicit feedback on topics related to the preliminary manufacturer impact analysis; (4) provide an opportunity early in the rulemaking process to express specific concerns to DOE; and (5) foster cooperation between manufacturers and DOE. During the manufacturer interviews, DOE discussed these and other issues regarding market data, distribution channels, anticipated consumer responses to standards, production and product mix, conversion costs, and cumulative regulatory burden. Appendix 12A of the preliminary TSD contains a complete copy of the interview guide.

DOE issued the preliminary analysis for this rulemaking on February 20, 2013 and published it in the *Federal Register* on February 28, 2013. 78 FR 13563. The preliminary analysis, as well as the complete preliminary TSD, is available at regulations.gov under docket number EERE-2011-BT-STD-0006. Links to these documents can also be found on DOE's website: www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24. The TSD includes the results of the following DOE preliminary analyses: (1) market and technology assessment; (2) screening analysis; (3) engineering analysis; (4) energy use characterization; (5) product price determinations; (6) LCC and PBP analyses; (7) shipments analysis; and (8) NIA.

DOE held a public meeting on April 9, 2013, to present the methodologies and results for the preliminary analyses. Manufacturers, trade associations, and environmental advocates attended the meeting. The participants discussed multiple issues, including the methodology and results of the market and technology assessment, screening analysis, engineering analysis, product price determination, energy use, life-cycle cost analysis, shipments, and NIA. Other issues brought up during the public meeting included regulatory authority and rulemaking schedule. Finally, the manufacturer impact analysis (MIA) and additional analyses that will be undertaken during the NOPR stage were discussed. The comments received during the public meeting, along with the written comments submitted to DOE since publication of the preliminary analysis, have contributed to DOE's proposed resolution of the issues in this rulemaking. A detailed discussion of comments from interested parties is available in the NOPR *Federal Register* notice for this rulemaking.

Following the publication of the preliminary analysis and the preliminary analysis public meeting, DOE held additional meetings with manufacturers as part of the consultative process for the MIA conducted during the NOPR phase. The interviews covered several key issues, including: (1) preliminary TSD follow-up; (2) key issues to this rulemaking; (3) a company overview and organizational characteristics; (4) manufacturer markups and profitability; (5) shipment projections; (6) financial parameters; (7) conversion costs; (8) cumulative regulatory burden; (9) direct employment impact assessment; (10) manufacturing capacity and non-US sales; (11) impact on competition; and (12) impacts on small business.

For the LCC, PBP, and NIA, DOE developed spreadsheets using Microsoft Excel®. The LCC and PBP spreadsheets calculate the economic impacts of replacing GSFLs and IRLs with

more efficacious lamps. The NIA spreadsheet calculates the national energy savings (NES) and national net present value (NPV) at various trial standard levels (TSLs) and includes a model that forecasts the impacts of energy conservation standards at various levels on product shipments. These spreadsheets are available on regulations.gov, docket number EERE-2011-BT-STD-0006 at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006.

1.5 STRUCTURE OF THE DOCUMENT

This NOPR TSD outlines the analytical approaches used in this rulemaking and consists of 18 chapters and 22 appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to the rulemaking for GSFLs and IRLs, and outlines the structure of the document
Chapter 2	Analytical Framework: describes the rulemaking process, and provides an overview of each analysis
Chapter 3	Market and Technology Assessment: characterizes the GSFL and IRL market and the technologies available for increasing efficacy, and outlines product classes
Chapter 4	Screening Analysis: determines which technology options are viable to consider in the engineering analysis
Chapter 5	Engineering Analysis: describes DOE's approach to the engineering analysis, and establishes efficacy levels based on lamp efficacy
Chapter 6	Energy Use Characterization: discusses the process used for generating energy use estimates for GSFLs and IRLs
Chapter 7	Product Price Determination: describes DOE's process for establishing the end-user prices for GSFLs and IRLs
Chapter 8	LCC and PBP Analyses: discusses the economic effects of standards on consumers and calculates the LCCs and PBPs of GSFLs and IRLs
Chapter 9	Life-Cycle Cost Consumer Sub-Group Analysis: discusses the economic effects of standards on certain consumer sub-groups and calculates the LCCs and PBPs for these consumers
Chapter 10	Trial Standard Levels: discusses the efficacy levels for each analyzed product class as they pertain to the TSLs chosen for GSFLs and IRLs
Chapter 11	Shipments Analysis: estimates shipments of the products over the 30-year analysis period that is used in performing the NIA, including how shipments may vary under alternative standard levels

Chapter 12	National Impact Analysis: assesses the NES, and the national NPV of total consumer costs and savings, expected to result from specific, potential energy conservation standards
Chapter 13	Manufacturer Impact Analysis: discusses the impacts of standards on the finances and profitability of GSFL and IRL manufacturers, and presents MIA results
Chapter 14	Emissions Analysis: discusses the effects of standards at each TSL on the emissions of three pollutants—sulfur dioxide (SO ₂), nitrogen oxides (NO _x) and mercury (Hg)—as well as on the emissions of carbon dioxide (CO ₂), methane (CH ₄), and nitrous oxide (N ₂ O)
Chapter 15	Monetization of Emission Reductions Benefits: discusses the basis for estimated monetary values used for the reduced emissions of CO ₂ and NO _x that are expected to result from each of the TSLs considered
Chapter 16	Utility Impact Analysis: discusses selected effects of proposed standards at each TSL on electric utilities
Chapter 17	Employment Impact Analysis: discusses the effects of proposed standards on national employment
Chapter 18	Regulatory Impact Analysis: discusses the impact of non-regulatory alternatives in comparison to efficiency standards
Appendix AA	Acronyms and Abbreviations: provides a set of acronyms and abbreviations used throughout this TSD.
Appendix 3A	Lighting Definitions in the United States Code and Code of Federal Regulations: provides a set of existing statutory and regulatory definitions for GSFLs and IRLs
Appendix 5A	Highly Efficacious Incandescent Reflector Lamps: details the information on highly efficacious prototype IRLs and the data that would be required to have considered them in the analysis
Appendix 5B	Modified Spectrum Incandescent Reflector Lamps: provides background on the definition of “modified spectrum” for IRLs and describes how DOE developed the factor used to set the efficacy requirements for the modified spectrum IRL product class
Appendix 6A	Lighting Controls: describes how DOE evaluated the effects of lighting controls
Appendix 7A	Additional End-User Price Results: provides end-user price results for additional products considered in the LCC and NIA

Appendix 7B	Rare Earth Phosphor Market Assessment and Impact on Consumers: reflects the rare earth phosphor market's impact on the LCC
Appendix 7C	Xenon Phosphor Market Assessment and Impact on Consumers: evaluates how the supply, market, and price of xenon affect its usability as a high-efficiency inert fill gas and its impact on the LCC
Appendix 8A	User Instructions for LCC and PBP Spreadsheet
Appendix 8B	Supplementary LCC and PBP Results: provides results for the Monte Carlo and sensitivity analyses
Appendix 8C	Residential Discount Rate Distributions: provides the probability distributions used with real interest rates to develop a residential discount rate
Appendix 8D	Hot Shock in Incandescent Reflector Lamps: describes the impact of hot shock on LCC savings for IRLs
Appendix 11A	Lighting Controls Market Penetration Projection: describes the assumptions and analysis DOE used to project changes in the penetration of lighting controls
Appendix 11B	Modeling of Rare Earth Price Impacts: describes the analysis DOE used to project the impact of rare earth oxide prices on GSFL prices
Appendix 12A	User Instructions for the NIA Spreadsheet
Appendix 12B	Rebound Effect: describes direct rebound effect and the analysis DOE used to establish its baseline rebound rate
Appendix 12C	Full-Fuel-Cycle Multipliers: summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from new standards Rebound Effect: describes direct rebound effect and the analysis DOE used to establish its baseline rebound rate
Appendix 13A	Manufacturer Interview Guide
Appendix 13B	Government Regulatory Impact Model Overview
Appendix 13C	Industry Net Present Value Results for Incandescent Reflector Lamps Shortened Lifetime Sensitivity: describes the impacts on industry net present value (INPV) for IRL manufacturers when manufacturers choose to shorten the lifetime of lamps to meet proposed efficacy levels.
Appendix 15A	Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866

- Appendix 15B Technical Update of Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866
- Appendix 18A Regulatory Impact Analysis: Supporting Materials

CHAPTER 2. ANALYTICAL FRAMEWORK

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CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

Sections 6295(o)(2)(A) and (3) of Title 42 United States Code (42 U.S.C. 6295(o)(2)(A) and (3)) require that energy conservation standards set by the U.S. Department of Energy (DOE) be technologically feasible and economically justified, and achieve the maximum improvement in energy efficiency. This chapter describes the general analytical framework that DOE uses in developing such standards, and in particular, standards for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). The analytical framework is a description of the methodology, the analytical tools, and relationships among the various analyses that are part of this rulemaking. For example, the methodology that addresses the statutory requirement for economic justification includes analyses of life-cycle cost (LCC); economic impact on manufacturers and users; national benefits; impacts, if any, on utility companies; and impacts, if any, from lessening competition among manufacturers. DOE will also solicit the views of the Department of Justice (DOJ) on any lessening of competition that is likely to result from the imposition of a proposed standard.

Figure 2.1.1 summarizes the analytical components of the standards-setting process. The central parts of this figure are the analyses contained in the boxes. The key inputs to the left and key outputs to the right show how the analyses fit into the rulemaking process, and how the analyses relate to each other. Key inputs are the types of data and information that the analyses require. Some key inputs exist in public databases; DOE collects other inputs from interested parties or persons with special knowledge. Key outputs are analytical results that feed directly into the standards-setting process. Dotted lines connecting analyses show types of information that feed from one analysis to another. While Figure 2.1.1 summarizes the inputs, outputs, and analyses of a typical standards rulemaking, individual inputs and outputs may vary by rulemaking.

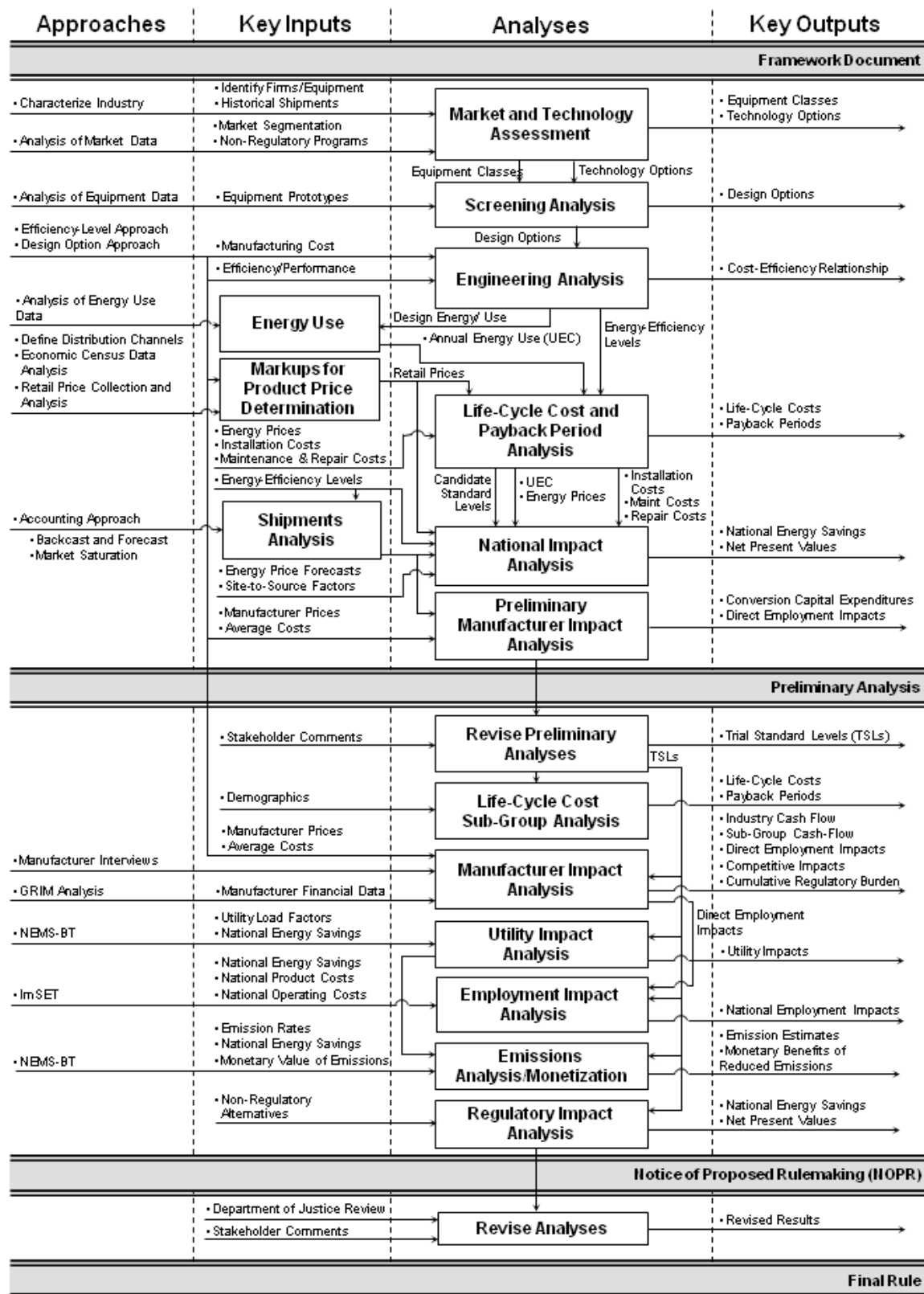


Figure 2.1.1 Flow Diagram of Analyses for the GSFL and IRL Rulemaking Process

The analyses performed in the notice of proposed rulemaking (NOPR) stage and reported in this technical support document (TSD) include:

- a market and technology assessment to characterize the GSFL and IRL markets, identify technology options that improve efficacy, and develop product classes;
- a screening analysis to review each technology option and determine if it is technologically feasible; practical to manufacture, install, and service; would adversely affect lamp utility or lamp availability; or would have adverse impacts on health and safety;
- an engineering analysis to study representative lamp systems and, as appropriate, lamp-and-ballast systems used as substitutes for baseline lamps, to select efficacy levels (ELs), and to determine lamp system power ratings;
- an energy-use characterization that generates energy-use estimates for covered GSFLs and IRLs;
- a product price determination that develops end-user product prices for the representative lamps identified in the engineering analysis;
- an LCC analysis that calculates, at the consumer level, the discounted savings in operating costs throughout the estimated average life of the lamp, compared to any increase in the installed costs likely to result directly from imposition of the standard;
- a payback period (PBP) analysis to estimate the amount of time it takes consumers to recover the higher purchase expense of more efficacious lamps through lower operating costs;
- an LCC subgroup analysis that evaluates the economic impacts on identifiable groups of consumers of GSFLs and IRLs, including various categories of lamp purchasers or owners who may experience disproportionate impacts from a national energy conservation standard;
- a shipments analysis to estimate yearly shipments of covered GSFLs and IRLs over the analysis period;
- a national impact analysis (NIA) that assesses the aggregate impacts at the national level of potential standards as measured by the net present value (NPV) of total consumer economic impacts and national energy savings (NES);
- a manufacturer impact analysis (MIA) that estimates the financial impact of proposed standards on lamp manufacturers and calculates impacts on competition, employment at the manufacturing plant, and manufacturing capacity;

- an emissions analysis to provide estimates of the effects of proposed standards on emissions of carbon dioxide (CO₂), sulfur dioxide (SO₂), nitrogen oxides (NO_x), and mercury (Hg);
- a monetization of reduction of emission benefits from proposed standards;
- a utility impact analysis (UIA) that estimates the effects of proposed standards on the installed capacity and the generating base of electric utilities;
- an employment impact analysis that estimates the indirect impacts of proposed standards on net jobs eliminated or created in the general economy as a consequence of increased spending on the installed price of GSFLs and IRLs and reduced consumer spending on energy; and
- a regulatory impact analysis (RIA) that presents major alternatives to proposed standards that may achieve comparable energy savings at a reasonable cost.

In response to comments it receives on the NOPR, DOE may revise some of its analyses before publishing the final rule.

2.2 BACKGROUND

As described in chapter 1 of this NOPR TSD, in September 1995, DOE announced a formal effort to consider further improvements to the process used to develop appliance efficiency standards. DOE called on energy efficiency groups, manufacturers, trade associations, state agencies, utilities, and other interested parties to provide input to this effort. As a result of this combined effort, the DOE published “Procedures, Interpretations and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products” (the “Process Rule”), 10 CFR part 430, subpart C, appendix A. The Process Rule outlined the procedural improvements identified by the interested parties and included a review of the: (1) economic models; (2) analytic tools; (3) methodologies; (4) non-regulatory approaches; and (5) prioritization of future rules. The Process Rule recommended that DOE take into account uncertainty and variability by carrying out scenario or probability analysis.

DOE developed the analytical framework for the GSFL and IRL rulemaking under the Process Rule. DOE documented this analytical framework in the “Energy Conservation Standards Rulemaking Framework Document for General Service Fluorescent Lamps and Incandescent Reflector Lamps” (hereafter, “Framework document”), and presented the analytical approach to stakeholders during a public meeting held on October 4, 2011 (hereafter “Framework public meeting”). This document is available at http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24. The following sections provide a general description of the different analytical components of the rulemaking framework.

2.3 MARKET AND TECHNOLOGY ASSESSMENT

The market and technology assessment characterizes the relevant product markets, identifies technology options to improve efficacy, and outlines proposed product classes. For more detail on the market and technology assessment, see chapter 3 of this NOPR TSD.

2.3.1 Market Assessment

When initiating a standards rulemaking, DOE develops information on the industry structure and market characteristics of the products concerned. This activity consists of both quantitative and qualitative efforts to assess the industry based on publicly available information. As such, DOE addresses: (1) industry structure and manufacturer market shares; (2) existing regulatory and non-regulatory efficiency improvement initiatives; and (3) trends in product characteristics and retail markets. This information serves as resource material throughout the rulemaking.

DOE has used and will use the most reliable and accurate data available at the time of each analysis in this rulemaking. DOE welcomes and will consider any submissions of additional data.

2.3.2 Technology Assessment

DOE typically uses information relating to existing technology options to develop more efficacious GSFL and IRL designs. DOE prepared a list of technologies for consideration that could improve the efficacy of GSFLs and IRLs. To develop this list, DOE reviewed manufacturer catalogs, recent trade publications, and technical journals, and consulted with technical experts.

2.3.3 Product Classes

When evaluating and establishing energy conservation standards, DOE divides covered products into classes by (a) the type of energy used; (b) the capacity of the product; or (c) other performance-related features that justify different standard levels, such as features affecting consumer utility. (See 42 U.S.C. 6295(q)) DOE then conducts its analysis and considers separate standard levels for each product class. DOE applied the criteria of 42 U.S.C. 6295(q) to GSFLs and IRLs to develop product classes for each product.

2.4 SCREENING ANALYSIS

The screening analysis examines the technology options identified in the technology assessment to determine as to whether they: (1) are technologically feasible; (2) are practical to manufacture, install, and service; (3) do not have an adverse impact on product utility or availability; and (4) do not have adverse impacts on health and safety. As described in section 2.3.2, DOE develops a list of technology options that can improve efficacy in consultation with industry, technical experts, and other interested parties. In the screening analysis, DOE reviews the list to determine if these technologies meet the screening criteria described above. In the engineering analysis, DOE only considers design options that meet all four of the screening criteria. For more detail on the screening analysis, see chapter 4 of this NOPR TSD.

2.5 ENGINEERING ANALYSIS

DOE derives ELs in the engineering analysis and end-user prices in the product price determination. By combining the results of the engineering analysis and the product price determination, DOE derives typical inputs for use in the LCC and NIA. The engineering analysis is generally based on commercially available lamps that incorporate the design options identified in the technology assessment and screening analysis. The methodology consists of the following steps: 1) selecting representative product classes, 2) selecting baseline lamps, 3) identifying more efficacious substitutes, and 4) developing ELs by directly analyzing representative product classes and then scaling those ELs to non-representative product classes. For more detail on the engineering analysis, see chapter 5 of this NOPR TSD.

2.5.1 Representative Product Classes

When a product has multiple product classes, DOE selects certain classes as “representative” and concentrates its analytical effort on these classes. DOE reviewed covered lamps and the associated product classes. DOE then identified and selected “representative” product classes to directly analyze. DOE chose these representative product classes primarily because of their high market volumes.

2.5.2 Baseline Lamps

For each representative product class, DOE selected a baseline lamp as a reference point against which to measure changes resulting from energy conservation standards. Typically, a baseline model is the most common, least efficacious lamp sold in a given product class. DOE also considered other lamp characteristics in choosing the most appropriate baseline for each product class such as wattage, lumen output, and lifetime.

2.5.3 More Efficacious Lamp Designs

DOE selected higher efficacy lamps as replacements for each of the baseline models considered. When selecting higher efficacy lamps, DOE considered only design options that meet the criteria outlined in the screening analysis. For GSFLs, DOE paired each lamp with an appropriate ballast because fluorescent lamps are a component of a system, and their performance is related to the ballast on which they operate.

2.5.4 Efficacy Levels

Having identified the more efficacious substitutes for each of the baseline lamps (or lamp-and-ballast systems), DOE developed ELs based on the consideration of several factors including: (1) the design options associated with the specific lamps being studied; (2) the ability of lamps across wattages to comply with the standard level of a given product class;¹ and (3) the

¹ ELs span multiple lamps of different wattages. For GSFLs, DOE ensured that full wattage lamps can meet all proposed ELs. For IRLs, DOE developed the proposed EL as a curve based on a continuous equation that specifies a minimum efficacy requirement across all wattages.

maximum technologically feasible EL. DOE then scales the ELs of representative product classes to those classes not directly analyzed.

2.6 ENERGY USE ANALYSIS

The energy use analysis provides estimates of annual energy consumption of representative lamps and lamp-and-ballast designs that DOE evaluates in the LCC and PBP analysis and the NIA. To develop annual energy consumption estimates, DOE multiplied annual usage (operating hours per year) by the system input power (rated in watts). To determine annual operating hours by sector and lamp type, DOE used data published in the 2010 U.S. Lighting Market Characterization² and Energy Information Administration's (EIA's) Commercial Building Energy Consumption Survey (CBECS),³ Residential Energy Consumption Survey (RECS),⁴ and the Manufacturing Energy Consumption Survey (MECS)⁵. For more detail on the energy use analysis, see chapter 6 of this NOPR TSD.

2.7 PRODUCT PRICE DETERMINATION

Typically, DOE develops manufacturer selling prices (MSPs) for covered products and applies markups to create end-user prices to use as inputs to the LCC analysis and NIA. Because GSFLs and IRLs are difficult to reverse-engineer (*i.e.*, not easily disassembled), DOE directly derives end-user prices for the lamps covered in this rulemaking. DOE estimates end-user prices for lamps by establishing discounts from manufacturer suggested price lists (hereafter "blue-book prices"). Based on feedback from manufacturer interviews, DOE determined that GSFLs and IRLs are sold through three main channels (state procurement, large distributors including do-it-yourself (DIY) stores (*i.e.*, Lowe's and Home Depot), and Internet retailers). Using these main channels and the gathered pricing data, DOE developed three different end-user prices as representative of a range of publicly available prices: low, based on the state procurement channel; medium, based on large distributors and DIY stores; and high, based on Internet retailers. DOE then developed an end-user price weighted by distribution channel to use in the main LCC analysis and NIA. DOE used the low and high end-user prices in sensitivity analyses conducted in the LCC. For more detail on the product price determination, see chapter 7 of this NOPR TSD.

² U.S. Department of Energy—Office of Energy Efficiency and Renewable Energy. *Final Report: 2010 U.S. Lighting Market Characterization*. 2012. Washington, D.C.

<http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>.

³ U.S. Department of Energy, Energy Information Administration. Commercial Building Energy Consumption Survey: Micro-level data, file 2 Building Activities, Special Measures of Size, and Multi-building Facilities. 2003. Washington, D.C. < www.eia.doe.gov/emeu/cbecs/public_use.html >.

⁴ U.S. Department of Energy, Energy Information Administration. RECS Public Use Microdata files. 2009. Washington, D.C. www.eia.gov/consumption/residential/data/2009/.

⁵ U.S. Department of Energy, Energy Information Administration. Manufacturing Energy Consumption Survey, Table 9.1: Enclosed Floorspace and Number of Establishment Buildings. 2006. Washington, D.C. www.eia.gov/emeu/mecs/mecs2006/2006tables.html.

2.8 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

DOE conducted LCC and PBP analyses to evaluate the economic impacts of potential standards on individual consumers using the efficacies and system input power ratings derived in the engineering analysis and the cost trends derived from the product price determination. The LCC is the total consumer expense over the life of a product, consisting of purchase, installation, and operating costs (operating costs are expenses for energy use, maintenance, and repair). The PBP is the estimated amount of time (in years) it takes consumers to recover the increased purchase cost (including installation) of a more efficient product through lower operating costs.

Inputs to the calculation of total installed cost include the cost of the product—which includes consumer product price and sales taxes—and installation costs. Inputs to the calculation of operating expenses include annual energy consumption, energy prices and price projections, repair and maintenance costs, product lifetimes, discount rates, and the year in which compliance with proposed standards would be required. For more detail on the LCC and PBP analysis, see chapter 8 of this NOPR TSD.

2.9 CONSUMER SUBGROUP ANALYSIS

A consumer subgroup comprises a subset of the population that could, for one reason or another, be affected disproportionately by new or amended energy conservation standards. DOE identified low-income consumers and institutions that serve low-income populations (*e.g.*, small nonprofits) as consumers that could be disproportionately impacted by the proposed standards. The LCC subgroup analysis evaluates the effects on these consumer subgroups by accounting for variations in key inputs to the LCC analysis. For more detail on the consumer subgroup analysis, see chapter 9 of this NOPR TSD.

2.10 TRIAL STANDARD LEVELS

Trial standard levels (TSLs) examine combinations of ELs across the different product classes for maximum technological feasibility, maximum energy savings, maximum NPV, and other metrics. For more detail on the TSLs, see chapter 10 of this NOPR TSD.

2.11 SHIPMENTS ANALYSIS

DOE uses projections of product shipments to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. DOE adopted a shipments model to estimate lamp shipments for this rulemaking. The shipments model has three main interacting elements: (1) a lamp demand module, which estimates the demand for GSFL and IRL lighting for each year of the analysis period; (2) a module that assigns shipments to product classes and ELs based on consumer sensitivities to first costs and operation and maintenance costs; and (3) a price learning module, which projects future prices based on historic price trends. The model allows product switching across appropriate product categories, constrained by substitution matrices, which specify the product choices available to consumers (lamps as well as lamp-and-ballast combinations for fluorescent lamps) depending on whether they are renovating lighting systems, installing lighting systems in new construction, or are simply replacing lamps. Scenarios were constructed to assess the potential impacts of uncertainties in the future

penetration of LEDs and lighting system controls into the GSFL and IRL markets and the potential impact of rare earth prices on GSFL prices.

The lamp demand module estimates the lumen demand for GSFL and IRL lighting. The lumen demand calculation assumes that the desired lighting capacity demand per unit floor area in each sector (*i.e.*, the maximum lumen output of installed lamps per square foot of floor space) remains fixed over the analysis period, and that lighting consumers will typically choose lighting products that maintain lumen capacity within 10 percent of baseline levels. Total floor space is assumed to change over the analysis period consistent with *AEO* 2013 projections. The increased use of lighting controls over the analysis period, projected as described in appendix 11A of this NOPR TSD, affects shipments by reducing average lamp hours of use, increasing lamp lifetimes, expressed in calendar years. The module also accounts for LED lighting penetration into the GSFL and IRL markets, in accordance with recent DOE projections. A lamp turnover calculation estimates demand for lamps in each year given the initial stock, the expected lifetimes of the lamps (and ballasts for GSFLs), and sector-specific assumptions on operating hours.

The module that assigns shipments to product classes and ELs based on consumer sensitivities to first costs and operation and maintenance costs selects which lamps are purchased in any given year, based on these sector-specific consumer sensitivities and the available lamp options, which were determined in the engineering analysis and the LCC analysis. The available options also depend on the case under consideration. In the base case, all lamp and ballast options are available. In each trial standard level only those lamp options at or above the EL set for a given product class are considered to be available. In this way, the module assigns market shares to the different product classes and ELs based on historical observations of consumer behavior. The consumer choice module incorporates a limit on the technology diffusion using a Bass diffusion curve based on historic rates of penetration of new lighting technologies into the market. It also accounts for other observed deviations from purely price and cost-driven behavior using an acceptance factor.

The price learning module estimates lamp and ballast prices in each year of the analysis period. Historical data on GSFL and IRL sales were fit to an experience curve that describes the relationship between price and cumulative shipments for U.S. consumption. Cumulative shipments are initialized based on historical shipments data. They are then augmented in each subsequent year of the analysis based on the shipments determined for the prior year by the module that assigns shipments to product classes and ELs based on consumer sensitivities to first costs and operation and maintenance costs. The current year's shipments, in turn, affect the subsequent year's prices.

For more detail on the shipments analysis, see chapter 11 of this NOPR TSD.

2.12 NATIONAL IMPACT ANALYSIS

The NIA assesses the NES and the NPV from a national perspective of total consumer costs and savings expected to result from new or amended energy conservation standards. Analyzing impacts of potential energy conservation standards for GSFLs and IRLs requires comparing projections of U.S. energy consumption with new or amended energy conservation

standards against projections of energy consumption without the standards. TSLs are specified by setting ELs for each product class.

Because the model allows for substitutions across product classes, to understand the impact of setting a standard at any given EL for any given product class, the impact on all other product classes must be considered. DOE analyzed the impacts of five TSLs, described in chapter 10 of this NOPR TSD. In addition to conducting the analysis for the rulemaking as a whole, DOE evaluated the NPV and NES by product class. DOE coded the NIA in a Microsoft Excel file available on regulations.gov, docket number EERE-2011-BT-STD-0006, allowing access to a broad range of scenario assumptions for conducting sensitivity analyses on specific input values. For more detail on the NIA, see chapter 12 of this NOPR TSD.

2.12.1 National Energy Savings Analysis

The inputs for determining the NES for each product class are: (1) lamp shipments; (2) annual energy consumption per unit; (3) stocks of lamps in each year; (4) national energy consumption; and (5) site-to-primary energy and fuel full cycle (FFC) conversion factors. The lamp stocks were calculated by the shipments model for each year of the analysis period from the prior year's stock, minus retirements, plus new shipments, accounting for lamp and ballast lifetimes. DOE calculated the national electricity consumption in each year by multiplying the number of units of each product class and EL in the stock by the corresponding power consumption and operating hours. The electricity savings are estimated from the difference in national electricity consumption between the base case (without new standards) and the standards cases for lamps shipped during the 2017-2046 period.

DOE has historically presented the NES in terms of primary energy savings. In response to the recommendations of a committee on "Point-of-Use and Full-Fuel-Cycle Measurement Approaches to Energy Efficiency Standards" appointed by the National Academy of Science, DOE announced its intention to use FFC measures of energy use and greenhouse gas (GHG) and other emissions in the national impact analyses and emissions analyses included in future energy conservation standards rulemakings. 76 FR 51281 (August 18, 2011). While DOE stated in that notice that it intended to use the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model to conduct the analysis, it also stated it would review alternative methods, including the use of NEMS. After evaluating both models and the approaches discussed in the August 18, 2011 notice, DOE has determined NEMS is a more appropriate tool for this application. 77 FR 49701 (Aug. 17, 2012). Therefore, DOE is using the NEMS model to conduct FFC analyses. For this analysis, DOE calculated FFC energy savings using the methodology described in appendix 12B of this NOPR TSD, which presents both the primary energy savings and the FFC energy savings for the considered candidate standard cases.

2.12.2 Net Present Value Analysis

The inputs for determining NPV are: (1) total annual installed cost; (2) total annual savings in operating costs; and (3) a discount factor to calculate the present value of costs and savings. DOE calculated net savings each year as the difference between the base case and each standards case in terms of total savings in operating costs versus total increases in installed costs. DOE calculated savings over the lifetime of products shipped in the 30-year analysis period.

DOE calculated NPV as the difference between the present value of operating-cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 and 7 percent to discount future costs and savings to present values.

For the NPV analysis, DOE calculates increases in total installed costs as the difference in total installed cost between the base case and the proposed standards case (*i.e.*, once the standards take effect). Because the more efficacious products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expresses savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

2.13 MANUFACTURER IMPACT ANALYSIS

DOE conducted separate MIAs for GSFLs and IRLs to estimate the financial impact of amended energy conservation standards on manufacturers of GSFLs and IRLs respectively, specifically to calculate the impact of such standards on domestic manufacturing employment and capacity for the two lamp technologies. The MIA has both quantitative and qualitative aspects. The quantitative part of the MIAs primarily relies on Government Regulatory Impact Models (GRIMs)—industry-cash-flow models customized for this rulemaking. The key GRIM inputs are data on the industry cost structure, product costs, shipments, and assumptions about markups and conversion costs. The key MIA output is industry net present value, or INPV. DOE used the GRIM to calculate cash flows using standard accounting principles and to compare changes in INPV between a base case and various TSLs (the standards case). The difference in INPV between the base and standards cases represents the financial impact of amended energy conservation standards on GSFL and IRL manufacturers. Different sets of assumptions (scenarios) produce different INPV results. The qualitative part of the MIA addresses factors such as manufacturing capacity; characteristics of, and impacts on, any particular subgroup of manufacturers; and impacts on competition.

DOE conducted the MIA in three phases. Phase 1, “Industry Profile,” consisted of the preparation of an industry characterization. Phase 2, “Industry Cash Flow,” focused on the industry as a whole using industry financial parameters derived in Phase 1 and the shipment scenarios used in the NIAs. In Phase 3, “Subgroup Impact Analysis,” DOE conducted structured, detailed interviews with a variety of GSFL and IRL manufacturers that account for more than 90 percent of domestic GSFL sales and more than 80 percent of domestic IRL sales covered by this rulemaking. During these interviews, DOE discussed engineering, manufacturing, procurement, and financial topics specific to each company and obtained each manufacturer’s view of the GSFL and IRL industries as a whole. The interviews provided valuable information that DOE used to evaluate the impacts of amended standards on manufacturers’ cash flows, manufacturing capacities, and employment levels.

For more detail on the MIA, see chapter 13 of this NOPR TSD.

2.14 EMISSIONS ANALYSIS

In the emissions analysis, DOE estimates the reduction in power sector emissions of carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfur dioxide (SO₂) and mercury (Hg) from potential energy conservation standards for the considered products. In addition, DOE will estimate emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as “upstream” emissions. Together, these emissions account for the FFC. In accordance with DOE’s FFC Statement of Policy (76 FR 51282 [Aug. 18, 2011]), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

DOE conducts the emissions analysis using emissions factors derived from data in the latest version of EIA’s *AEO*, supplemented by data from other sources. EIA prepares the Annual Energy Outlook using NEMS. Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO* 2013, which generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of December 31, 2012.

SO₂ emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO₂ for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO₂ emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those states and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remained in effect. See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008). On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. *AEO* 2013 assumes that CAIR remains a binding regulation through 2040.

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO₂ emissions allowances resulting from the lower electricity demand caused by the adoption of an efficiency standard could be used to permit offsetting increases in SO₂ emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO₂ emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO₂ as a result of standards.

Beginning in 2015, however, SO₂ emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for HCl as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for

SO₂ (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO₂ emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2013* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO₂ emissions. Under the MATS, NEMS shows a reduction in SO₂ emissions when electricity demand decreases (*e.g.*, as a result of energy efficiency standards). Emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO₂ emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO₂ emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO₂ emissions in 2015 and beyond.

CAIR established a cap on NO_x emissions in eastern states and the District of Columbia. Energy conservation standards are expected to have little or no physical effect on these emissions in those states covered by CAIR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the states not affected by the caps, so DOE estimates NO_x emissions reductions from potential standards in the states where emissions are not capped.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For this rulemaking, DOE estimated mercury emissions reductions using emissions factors based on *AEO 2013*, which incorporates the MATS.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO₂ and NO_x. The monetary benefits that DOE estimates for reductions in SO₂ and NO_x emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

For more detail on the emissions analysis, see chapter 14 of this NOPR TSD.

2.15 MONETIZING CARBON DIOXIDE AND OTHER EMISSIONS REDUCTIONS

DOE estimates the monetary benefits likely to result from the reduced emissions of CO₂ and NO_x that are expected to result from each of the standard levels considered.

To estimate the monetary value of benefits resulting from reduced emissions of CO₂ emissions, DOE uses the most current Social Cost of Carbon (SCC) values developed by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural

productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on SCC released an update of its previous report in 2013.⁶ The most recent estimates of the SCC in 2015, expressed in 2012\$, are \$12.9, \$40.8, \$62.2, and \$117 per metric ton of CO₂ avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO₂ emissions.

DOE multiplies the CO₂ emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO₂ and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_x emissions resulting from the standard levels it considers. For NO_x emissions, available estimates suggest a very wide range of monetary values, ranging from \$468 to \$4,809 per ton in 2012\$).⁷ DOE calculates monetary benefits using a medium value for NO_x emissions of \$2,639 per short ton (in 2012\$), and real discount rates of 3 percent and 7 percent.

DOE is evaluating appropriate valuation of Hg and SO₂ emissions. DOE has not monetized estimates of SO₂ and Hg reduction in this rulemaking.

For more detail on the monetization of emissions reductions, see chapter 15 of this NOPR TSD.

2.16 UTILITY IMPACT ANALYSIS

To estimate the impacts of potential energy conservation standards for furnace fans on the electric utility industry, DOE uses a variant of the EIA's National Energy Modeling System

⁶ *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, May 2013.

http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf

⁷ For additional information, refer to U.S. Office of Management and Budget, Office of Information and Regulatory Affairs, *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*, Washington, DC.

called NEMS-BT.⁸ NEMS is a large, multi-sectoral, partial-equilibrium model of the U.S. energy sector that EIA has developed over several years, primarily for the purpose of preparing the *AEO*. NEMS produces a widely recognized forecast for the United States through 2035 and is available to the public.

The UIA is a comparison between the NEMS-BT model results for the base case and standard cases. The UIA reports the changes in installed capacity and generation that result from each standard level by plant type. DOE models the anticipated energy savings impacts from potential amended energy conservation standards using NEMS-BT to generate forecasts that deviate from the *AEO* Reference Case.

For more detail on the utility impact analysis, see chapter 16 of this NOPR TSD.

2.17 EMPLOYMENT IMPACT ANALYSIS

The adoption of energy conservation standards can affect employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered products. DOE evaluates direct employment impacts in the MIA.

Indirect employment impacts may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to standards. DOE defines indirect employment impacts from standards as net jobs eliminated or created in the general economy as a result of increased spending driven by increased product prices and reduced spending on energy.

The indirect employment impacts are investigated in the employment impact analysis using the Pacific Northwest National Laboratory's "Impact of Sector Energy Technologies" (ImSET) model.⁹ The ImSET model was developed for DOE's Office of Planning, Budget, and Analysis to estimate the employment and income effects of energy-saving technologies in buildings, industry, and transportation. Compared with simple economic multiplier approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy conservation investments.

For more detail on the employment impact analysis, see chapter 17 of this NOPR TSD.

⁸ For more information on NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview*, DOE/EIA-0581 (October 2009), available at: <http://www.eia.gov/oiaf/aeo/overview/#overview>. EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on EIA assumptions, DOE refers to the model by the name NEMS-BT. ("BT" refers to DOE's Building Technologies Program, under whose aegis this work is performed.)

⁹ Roop, J. M., M. J. Scott, and R. W. Schultz, "ImSET: Impact of Sector Energy Technologies," PNNL-15273. Pacific Northwest National Laboratory (2005).

2.18 REGULATORY IMPACT ANALYSIS

In the NOPR stage, DOE prepared a RIA that evaluates potential non-regulatory policy alternatives, comparing the costs and benefits of each to those of the proposed standards. DOE recognizes that non-regulatory policy alternatives can substantially affect energy efficiency or reduce energy consumption. DOE bases its assessment on the actual impacts of any such initiatives to date, but also considers information presented by interested parties regarding the potential future impacts of current initiatives. For more detail on the regulatory impact analysis, see chapter 18 of this NOPR TSD.

2.19 DEPARTMENT OF JUSTICE REVIEW

Section 325(o)(2)(B)(i)(V) of the Energy Policy and Conservation Act states that, before the Secretary of Energy may prescribe a new or amended energy conservation standard, the Secretary shall ask the U.S. Attorney General to make a determination of “the impact of any lessening of competition...that is likely to result from the imposition of the standard.” (42 U.S.C. 6295) Pursuant to this requirement, DOE will solicit the views of DOJ on any lessening of competition that is likely to result from the imposition of a proposed standard and will give the views provided full consideration in assessing economic justification of a proposed standard.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

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CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter consists of four sections: scope of coverage, market assessment, the technology assessment, and product classes. The scope of coverage describes the products covered under this rulemaking and discusses certain amendments to the definitions of these products being proposed by the U.S. Department of Energy (DOE). The market assessment provides an overall picture of the market for the products concerned, including the nature of the products, industry structure, and manufacturer market shares; regulatory and non-regulatory efficiency improvement programs; market trends; and quantities of products sold. The technology assessment identifies a list of technologies DOE is proposing to be evaluated in the screening analysis. The product classes section discusses the class-setting factors DOE is proposing for this rulemaking.

The information DOE gathers from the market and technology assessment serves as resource material for use throughout the rulemaking. DOE considers both quantitative and qualitative information from publicly available sources and interested parties.

3.2 SCOPE OF COVERAGE

The following sections describe in more detail the definitions for both general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs) that are covered in this rulemaking. Further, DOE evaluates clarifications of certain exemptions in the definition of “general service fluorescent lamp,” and discusses extending standards to additional GSFL types; and including additional IRLs in the scope of coverage.

3.2.1 General Service Fluorescent Lamps

Section 321 of the Energy Policy and Conservation Act (EPCA; 42 U.S.C. 6291 *et seq.*) contains definitions for fluorescent lamps and associated terms. DOE codified the statutory definitions and definitions of supplementary terms for fluorescent lamps in the Code of Federal Regulations (CFR). 10 CFR 430.2. These definitions are provided below and also listed in appendix 3A of this notice of proposed rulemaking (NOPR) technical support document (TSD).

3.2.1.1 Current CFR Definitions

10 CFR 430.2 defines a fluorescent lamp and general service fluorescent lamp as follows:

Fluorescent lamp means a low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light, including only the following:

- (1) Any straight-shaped lamp (commonly referred to as 4-foot medium bipin lamps) with medium bipin bases of nominal overall length of 48 inches and rated wattage of 25 or more;
- (2) Any U-shaped lamp (commonly referred to as 2-foot U-shaped lamps) with medium bipin bases of nominal overall length between 22 and 25 inches and rated wattage of 25 or more;
- (3) Any rapid start lamp (commonly referred to as 8-foot high output lamps) with recessed double contact bases of nominal overall length of 96 inches;

- (4) Any instant start lamp (commonly referred to as 8-foot slimline lamps) with single pin bases of nominal overall length of 96 inches and rated wattage of 52 or more;
- (5) Any straight-shaped lamp (commonly referred to as 4-foot miniature bipin standard output lamps) with miniature bipin bases of nominal overall length between 45 and 48 inches and rated wattage of 26 or more; and
- (6) Any straight-shaped lamp (commonly referred to 4-foot miniature bipin high output lamps) with miniature bipin bases of nominal overall length between 45 and 48 inches and rated wattage of 49 or more.

General service fluorescent lamp means any fluorescent lamp which can be used to satisfy the majority of fluorescent lighting applications, but does not include any lamp designed and marketed for the following nongeneral application:

- (1) Fluorescent lamps designed to promote plant growth;
- (2) Fluorescent lamps specifically designed for cold temperature applications;
- (3) Colored fluorescent lamps;
- (4) Impact-resistant fluorescent lamps;
- (5) Reflectorized or aperture lamps;
- (6) Fluorescent lamps designed for use in reprographic equipment;
- (7) Lamps primarily designed to produce radiation in the ultra-violet region of the spectrum; and
- (8) Lamps with a Color Rendering Index of 87 or greater.

10 CFR 430.2

3.2.1.2 Clarification of GSFL Definitions

DOE received several queries from the general public on the application of the exemptions listed in the GSFL definition. DOE believes that further clarity should be provided for these exemptions. DOE evaluated each one and found that “impact-resistant fluorescent lamps” and “reflectorized or aperture lamps” were the only two exemptions and “use in reprographic material” and “the ultra-violet region of the spectrum” were the only two terms not defined elsewhere or the application of the exemption was not clearly stated. For example, “colored fluorescent lamps” are already defined separately within the CFR and “fluorescent lamps designed to promote plant growth” clearly specifies the function of the lamps such that their identification is unambiguous. To provide further clarification on the terms “impact-resistant,” “reflectorized or aperture,” “reprographic equipment,” and “ultra-violet region of the spectrum,” DOE examined industry bulletins, product literature, and other online publications. Through this research and manufacturer interviews, DOE has found “impact-resistant” to be synonymous with “shatter-resistant” and is proposing a definition for “impact-resistant fluorescent lamp” based on the existing definition of “shatter-resistant lamp” in 10 CFR 430.2 as follows:

Impact-resistant fluorescent lamp means a lamp that:

- a. Has a coating or equivalent technology that is compliant with NSF/ANSI 51 (incorporated by reference; *see* §430.3) and is designed to contain the glass if the glass envelope of the lamp is broken; and
- b. Is designated and marketed for the intended application, with
 - i. The designation on the lamp packaging; and

- ii. Marketing materials that identify the lamp as being impact-resistant, shatter-resistant, shatter-proof, or shatter-protected.

Product literature, industry bulletins, and online publications indicated that “reflectorized or aperture lamp” refers to lamps that contain an inner reflective coating on the bulb to direct emitted light. Therefore, DOE is proposing to define “reflectorized or aperture lamp” as follows:

Reflectorized or aperture lamp means a fluorescent lamp that contains an inner reflective coating on the bulb to direct the light.

Additionally, DOE is proposing adding more detail for “use in reprographic material” and “the ultra-violet region of the spectrum” to provide a better understanding of DOE’s interpretation of these terms. DOE has found that “fluorescent lamp[s] designed for use in reprographic equipment” are intended for use in equipment that is used to reproduce, reprint, or copy graphic material. Therefore, DOE is proposing defining “fluorescent lamps designed for use in reprographic equipment” as follows:

Fluorescent lamps designed for use in reprographic equipment means fluorescent lamps incorporated in equipment used to reproduce, reprint, or copy graphic material.

Concerning “lamps primarily designed to produce radiation in the ultra-violet region of the spectrum,” DOE determined that the term “ultra-violet region of the spectrum” refers to the portion of the electromagnetic spectrum where light has a wavelength between 10 and 400 nanometers. Therefore, DOE is proposing adding detail to the exemption as follows:

Lamps primarily designed to produce radiation in the ultra-violet region of the spectrum mean fluorescent lamps that primarily emit light in the portion of the electromagnetic spectrum where light has a wavelength between 10 and 400 nanometers.

DOE is also proposing to clarify references of “designed” and “marketed” as applied to definitions of lighting products covered under DOE standards as follows: the terms “designed,” “designated,” “designation,” “designated and marketed,” and “designed and marketed” for covered lighting products to mean that in a publicly available document (*e.g.*, product literature, catalogs, labels), manufacturers explicitly state the application for which the lamp is intended. These terms are generally used to restrict lamps to use in certain intended applications and/or functions and to limit potential loopholes.

3.2.1.3 Additional GSFL Wattages

In its review of the market, DOE determined that there are fluorescent lamps with lower wattages than those specified in DOE’s definition. Specifically, DOE found lower wattage lamps for the 8-foot single pin (SP) slimline, 4-foot T5 miniature bipin (MiniBP) standard output (SO), and 4-foot T5 MiniBP high output (HO) lamp types. DOE currently covers 8-foot SP slimline lamps with wattages of 52 W or more. The 8-foot SP slimline lamps are now being offered in lower wattages of 49 W, 50 W, and 51 W. DOE currently covers 4-foot T5 MiniBP SO lamps with wattages of 26 W or more. The 4-foot T5 MiniBP SO lamps are now being offered at a

lower wattage of 25 W. DOE currently covers 4-foot T5 MiniBP HO lamps with wattages of 49 W or more. The 4-foot T5 MiniBP HO lamps are now being offered at lower wattages of 44 W and 47 W. These reduced wattage lamps are generally more efficacious than their full wattage counterparts and, because of their lower wattage, offer the potential for increased energy savings. Further, manufacturer feedback indicated that the lower wattage lamp market will only grow in size. Therefore, DOE is proposing to extend coverage to the following GSFLs:

- 8-foot SP slimline lamps with wattages ≥ 49 W and < 52 W;
- 4-foot MiniBP SO lamps with wattages ≥ 25 W and < 26 W; and
- 4-foot MiniBP HO lamps with wattages ≥ 44 W and < 49 W.

3.2.1.4 Additional GSFL Types

As part of this energy conservation standards rulemaking, DOE is directed to evaluate energy efficiency standards for additional GSFLs beyond those already covered. 42 U.S.C. 6295 (i)(5) To identify the potential additional GSFLs, DOE first reviewed the fluorescent lighting market and identified lamps that meet the general description of a “fluorescent lamp” in the introductory language of 42 U.S.C. 6291(30)(A), that can be used to satisfy the majority of fluorescent lighting applications, that are not within the exclusions specified in 42 U.S.C. 6291(30)(B), and for which EPCA does not already prescribe standards. 73 FR 13629, 13620 (March 13, 2008). For each additional GSFL identified, DOE then assessed whether standards for such lamps would result in significant energy savings and, further, if such standards are technologically feasible and economically justified. Standards for any applicable additional GSFL are adopted based on the same criteria used to set new or amended standards for products per 42 U.S.C. 6295(o).

Fluorescent lamps come in three primary shapes: linear, U-shaped, and circline. Current standards cover certain linear and U-shaped lamps. There is little publicly available information on the installed stock and energy consumption of circline lamps. The 2010 U.S. Lighting Market Characterization (LMC) report includes these lamps under the miscellaneous category for fluorescent lamps, which composed 2.1 percent of lighting and consumed 4 terrawatt-hour (TWh) of electricity in 2010.^a Circline lamps would only be a small portion of the installed stock and energy consumption of this category, which includes all fluorescents other than T5 linear and T8 and T12 linear and U-shaped lamps, as well as fluorescent lamps with unknown characteristics. The low levels of installed stock and energy consumption for these alternate-shaped fluorescent lamps indicate limited potential for energy savings. Additionally, feedback from manufacturer interviews confirmed that fluorescent lamps in shapes not covered do not comprise a significant portion of the market. Based on this analysis DOE is not proposing to extend coverage to fluorescent lamps with shapes not currently covered.

DOE’s assessment of linear fluorescent lamps with lengths not covered shows that standards for these lamp types would not likely result in significant energy savings. Linear

^a U.S. Department of Energy. *2010 U.S. Lighting Market Characterization*. January 2012. Available at <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>.

medium bipin (MBP) lamps come in lengths ranging from 1 to 6 feet and are mainly T8 and T12 diameters. Currently only 4-foot MBP linear lamps are covered by standards. DOE's analysis shows that 5- and 6-foot linear fluorescent lamps compose a very low percentage of the linear MBP product offerings. For the T8 MBP lamps with lengths less than 4 feet, according to the 2010 LMC, these lamps composed about 0.2 percent of all installed lighting and 0.7 percent of the fluorescent lamp market and consumed 1 TWh of electricity in 2010.^b The installed inventory of T12 MBP lamps with lengths less than 4 feet is even less than the T8 lamps. Additionally, DOE focused on T8 lamps as energy conservation standards for ballasts that require compliance November 14, 2014 will be difficult for T12 ballasts to meet, likely resulting in a shift away from T12 lamps. 76 FR 70548 (Nov. 14, 2011)

Hence, the low levels of installed stock and energy consumption of these lamps indicate limited potential for energy savings. Further, in interviews manufacturers confirmed that linear fluorescent lamps with alternate lengths do not represent a significant portion of the market. Based on this analysis, DOE is not proposing to extend coverage to linear fluorescent lamps with lengths not currently covered.

Additionally, DOE determined that compact fluorescent lamps (CFLs) are included in the "general service lamps" definition, which also mentions general service incandescent lamps, general service light-emitting diode lamps, and organic light-emitting diode lamps, but excludes any general service fluorescent lamp. DOE has determined that the term "compact fluorescent lamps" in this definition includes both pin base and medium base CFLs. Under 42 U.S.C. 6295(i)(6), DOE is required to initiate a rulemaking for general service lamps no later than January 2014. This requirement indicates that it was intended for DOE to establish standards for lamps categorized as general service lamps, including CFLs, in a rulemaking separate from GSFLs. Therefore, DOE has determined that CFLs do not fall within the scope of this rulemaking.

3.2.2 Incandescent Reflector Lamps

As with GSFLs, DOE codified the statutory definitions and definitions of supplementary terms for IRLs in the CFR. The definition of "incandescent reflector lamp" contains several terms that limit the scope of IRLs. Appendix 3A of this NOPR TSD contains statutory and CFR definitions for many of these terms. 10 CFR 430.2 defines an incandescent reflector lamp as:

Incandescent reflector lamp (commonly referred to as a reflector lamp) means any lamp in which light is produced by a filament heated to incandescence by an electric current, which: is not colored or designed for rough or vibration service applications that contains an inner reflective coating on the outer bulb to direct the light; has an R, PAR, ER, BR, BPAR^c, or similar bulb shapes with an E26 medium screw base; has a rated voltage or voltage range that lies at least partially in the range of 115 and 130 volts; has a diameter that exceeds 2.25 inches; and has a rated wattage that is 40 watts or higher.

^b U.S. Department of Energy. 2010 *U.S. Lighting Market Characterization*. January 2012. Available at <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>.

^c Lamp shapes: R (reflector), PAR (parabolic aluminized reflector), ER (elliptical reflector); BR (bulged reflector), BPAR (bulged parabolic aluminum reflector)

Certain reflector (R), elliptical reflector (ER), and bulged reflector (BR) IRLs are covered by this definition but are not included in this rulemaking. Section 322(b) of EISA 2007, in amending EPCA to set forth revised standards for IRLs in new section 325(i)(1)(C), exempted from these standards the following categories of IRLs: (1) lamps rated 50 watts or less that are ER30, BR30, BR40, or ER40; (2) lamps rated 65 watts that are BR30, BR40, or ER40 lamps; and (3) R20 incandescent reflector lamps rated 45 watts or less. (42 U.S.C. 6295(i)(C)) (DOE refers to these three categories of lamps collectively as “certain R, ER, and BR IRLs.”) DOE subsequently determined that this EISA 2007 amendment exempted these lamps from regulations that existed at that time but did not preclude them from future regulations. However, because the rulemaking process for the first cycle of amendments to GSFL and IRL standards per 42 U.S.C. 6295(i)(5) (hereafter “2009 Lamps Rule”)^d was already underway, DOE decided to initiate a separate rulemaking for these certain R, ER, and BR IRLs. Therefore, DOE is not proposing to amend standards for these products in this rulemaking.

With respect to wattage, while the definition requires IRLs to have a “rated wattage that is 40 watts or higher,” current IRL standards are set for the 40-205 W range. DOE assessed this upper limit of the wattage range for covered IRLs. Based on a review of manufacturer catalogs, DOE determined that IRLs with rated wattages greater than 205 W compose a very small portion of the market and, therefore, do not represent substantial potential energy savings. Furthermore, many of these products are designed for specialty uses such as heating and drying in industrial and commercial applications, or for use in swimming pools. For these reasons, DOE is not proposing coverage for IRLs with rated wattages greater than 205 W.

3.3 MARKET ASSESSMENT

For both GSFLs and IRLs, the following market assessment identifies the relevant manufacturer trade association and domestic manufacturers; discusses manufacturer market share, regulatory programs, and non-regulatory initiatives; defines product classes; and provides historical shipment data.

3.3.1 Trade Association

The National Electrical Manufacturers Association (NEMA) is the trade association for GSFLs and IRLs. NEMA’s Lighting Systems Division is one of ten product divisions, and is further divided into six product sections. The Lamp Section’s 27 member companies compose, according to manufacturer interviews, about 90 percent of the U.S. GSFL and IRL markets. In addition to GSFLs and IRLs, NEMA’s Lighting Systems Division also oversees products such as ballasts, emergency lighting, lighting controls, luminaires, solid state lighting, and other emerging lighting technologies. NEMA provides an organization through which manufacturers of lighting products can work together on projects that affect their industry and businesses. NEMA’s activities relating to energy efficiency include:¹

^d The final rule for this first cycle of amendments to GSFL and IRL standards was published in July 2009. 74 FR 34080 (July 14, 2009).

- “[a]dvising the U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) on lighting research and market transformation needs;
- engaging in legislative work on energy and lighting issues;
- monitoring energy-efficiency rulemakings and standards affecting lighting products by federal and state agencies;
- supporting adoption of ASHRAE/IESNA 90.1 lighting provisions;
- working with market transformation and environmental groups to advance market use of energy-efficient lighting technologies;
- advising DOE and EPA on ENERGY STAR Buildings and ENERGY STAR voluntary product labeling programs; and
- advocating market-based approaches to enhance the use and penetration of energy-efficient technologies.”

3.3.2 Manufacturers and Market Share

The following list contains the names of manufacturers that produce GSFLs:

- Atlas Lighting Products, Inc.
- Bulbrite Industries, Inc.
- EiKO, Ltd.
- Feit Electric Company, Inc.
- GE Consumer & Industrial
- Halco Lighting Technologies
- Havells USA
- Litetronics International, Inc.
- LumaPro
- MaxLite
- OSRAM SYLVANIA Inc.
- OttLite Technologies Inc.
- Philips Lighting Company
- Plusrite Electric (China) Co., Ltd.
- Satco Products, Inc.
- SLI Lighting
- Technical Consumer Products, Inc.
- Topaz Lighting Corp.
- Universal Lighting Technologies
- Ushio America, Inc.
- Westinghouse Lighting Corporation

The following list contains the names of manufacturers that produce IRLs:

- Advanced Lighting Technologies Inc.
- Bulbrite Industries, Inc.
- EiKO, Ltd.
- EYE Lighting International of N.A., Inc.

- Feit Electric Company, Inc.
- GE Consumer & Industrial
- Green Energy Lighting Corp.
- Halco Lighting Technologies
- Havells USA
- Howard Industries Inc.
- Litetronics International, Inc.
- OSRAM SYLVANIA Inc.
- Philips Lighting Company
- Premium Quality Lighting, Inc.
- RAB Lighting
- Satco Products, Inc.
- SLi Lighting
- Technical Consumer Products, Inc.
- Utilitech
- Ushio America, Inc.
- Westinghouse Lighting Corporation

The GSFL and IRL industries are characterized by both domestic and international manufacturers. The majority of covered GSFLs and IRLs are manufactured by three large companies. The three manufacturers that hold the majority of the domestic market share of GSFLs and IRLs are the following:

- GE Consumer and Industrial of General Electric, Inc. (hereafter “GE”)
- OSRAM SYLVANIA of Siemens AG (hereafter “OSI”)
- Philips Lighting Company of Philips Electronics North America Corporation (hereafter “Philips”)

In addition to lamps listed under this rulemaking, the lighting divisions of all three companies manufacture other products, such as ballasts, high intensity discharge lamps, light-emitting diodes (LEDs), and CFLs.

3.3.2.1 Small Businesses

Small businesses may be particularly affected by the promulgation of minimum energy conservation standards for GSFLs and IRLs. The Small Business Administration (SBA) lists small business size standards that are matched to industries as they are described in the North American Industry Classification System (NAICS). A size standard is the largest that a for-profit concern can be and still qualify as a small business for federal government programs. These size standards are generally the average annual receipts or the average employment of a firm. For lamps, the size standard is matched to NAICS code 335110, *Electric Lamp Bulb and Part Manufacturing*, which has a size standard of 1,000 employees or fewer.²

DOE studies the potential impacts on these small businesses in detail as part of the manufacturer impact analysis. For more information see chapter 13 of this TSD.

3.3.3 Regulatory Programs

Several federal and international regulatory programs affect the markets for GSFLs and IRLs. The following section summarizes U.S., Canadian, and European regulatory initiatives relevant to the lamps covered by this rulemaking. While the following discussion is not exhaustive in describing all regulatory action related to GSFLs and IRLs, it provides detail on some notable initiatives that characterize recent developments in the lighting market.

3.3.3.1 GSFL Federal Energy Conservation Standards

EPCA established an energy conservation program for major household appliances. Additional amendments to EPCA gave DOE the authority to regulate the energy efficiency of several products, including certain GSFLs. Specifically, the Energy Policy Act of 1992 (EPAct 1992), Pub. L. 102-486, established energy conservation standards for 4-foot MBP, 2-foot U-shaped, 8-foot SP slimline, and 8-foot recessed double contact (RDC) HO GSFLs. The standards mandate that lamps manufactured on or after the specified effective dates must meet the minimum color rendering index (CRI) and minimum average lamp efficacy requirements. (42 U.S.C. 6295(i)(1)); 10 CFR Section 430.32(n)(1) Table 3.3.1 presents these federal standards.

Table 3.3.1 EPAct 1992 Federal Regulations for General Service Fluorescent Lamps

Lamp Type	Nominal Lamp Wattage	Minimum CRI	Minimum Average Lamp Efficacy <i>lm/W</i>	Effective Date
4-foot medium bipin	> 35 W	69	75.0	Nov. 1, 1995
	≤ 35 W	45	75.0	Nov. 1, 1995
2-foot U-shaped	> 35 W	69	68.0	Nov. 1, 1995
	≤ 35 W	45	64.0	Nov. 1, 1995
8-foot slimline ^c	> 65 W	69	80.0	May 1, 1994
	≤ 65 W ^f	45	80.0	May 1, 1994
8-foot high output	> 100 W	69	80.0	May 1, 1994
	≤ 100 W	45	80.0	May 1, 1994

EPCA directs DOE to conduct two cycles of rulemakings to determine whether to amend GSFL standards, and to determine whether to adopt standards for additional types of GSFLs. (42 U.S.C. 6295(i)(3)–(5)) Today’s rulemaking represents the second rulemaking to evaluate amending the GSFL energy conservation standards. The first rulemaking, the 2009 Lamps Rule, resulted in a final rule published in the *Federal Register* on July 14, 2009, which, as directed by 42 U.S.C. 6295(i)(3), altered EPAct 1992 standards and, as directed by 42 U.S.C. 6295(i)(5), also adopted energy conservation standards for additional GSFLs. 74 FR 34080. The 2009 Lamps Rule adopted the lamp efficacy standards shown in Table 3.3.2 for GSFLs manufactured after July 14, 2012. 10 CFR Section 430.32(n)(3)

^c Shown correctly in this table; as written in the CFR, the ≤35 W class was misattributed to 8-foot slimline lamps.

^f Shown correctly in this table; as written in the CFR, “>65 W” is erroneously repeated in this cell.

Table 3.3.2 2009 Lamps Rule Federal Regulations for General Service Fluorescent Lamps

Lamp Type	Correlated Color Temperature	Minimum Average Lamp Efficacy <i>lm/W</i>
4-foot medium bipin	≤ 4,500 K	89
	> 4,500 K and ≤ 7,000 K	88
2-foot U-shaped	≤ 4,500 K	84
	> 4,500 K and ≤ 7,000 K	81
8-foot slimline	≤ 4,500 K	97
	> 4,500 K and ≤ 7,000 K	93
8-foot high output	≤ 4,500 K	92
	> 4,500 K and ≤ 7,000 K	88
4-foot miniature bipin standard output	≤ 4,500 K	86
	> 4,500 K and ≤ 7,000 K	81
4-foot miniature bipin high output	≤ 4,500 K	76
	> 4,500 K and ≤ 7,000 K	72

3.3.3.2 IRL Federal Energy Conservation Standards

As with GSFLs, amendments to EPCA in EPAct 1992 established energy conservation standards for IRLs. (42 U.S.C. 6291(1) and 42 U.S.C. 6295(i)(1)) In addition, subsequent amendments to EPCA in the Energy Independence and Security Act of 2007 (EISA 2007), Pub. L. 110-140, amended the existing standards for IRLs. Table 3.3.3 outlines these amended standards. EPCA mandated that all lamps manufactured after November 1, 1995 meet six efficacy requirements with minimum lamp efficacy varying by nominal lamp wattage. EISA 2007 amended EPCA's definition for IRL and amended the standard in 42 U.S.C. 6295(i)(1). Prior to EISA 2007, the statutory definition for IRLs excluded ER- and BR-shaped lamps and lamps with a diameter less than 2.75 inches. EISA 2007 amended this definition to include ER- and BR-shaped lamps and lamps with diameters greater than 2.25 inches. EISA 2007 also amended 42 U.S.C. 6295(i)(1) to exempt the following lamps from the minimum efficacy requirements: (1) lamps rated at 50 W or less that are ER30, BR30, BR40, and ER40; (2) lamps rated at 65 W that are BR30, BR40, or ER40 lamps; and (3) R20 IRLs rated 45 W or less.

Table 3.3.3 EPAct 1992 Federal Regulations for IRLs

Nominal Lamp Wattage <i>W</i>	Minimum Average Lamp Efficacy <i>lm/W</i>
40-50	10.5
51-66	11.0
67-85	12.5
86-115	14.0
116-155	14.5
156-205	15.0

Along with GSFL standards, EPCA directs DOE to conduct two cycles of rulemakings to determine whether to amend IRL standards. (42 U.S.C. 6295(i)(3)–(5)) Today's rulemaking represents the second rulemaking to evaluate amending the IRL energy conservation standards. The first rulemaking, the 2009 Lamps Rule, resulted in a final rule that, as directed by 42 U.S.C.

6295(i)(3), amended EPL Act 1992 standards for covered IRLs manufactured after July 14, 2012, as shown in Table 3.3.4. 10 CFR Section 430.32(n)(5)

Table 3.3.4 2009 Lamps Rule Federal Regulations for IRLs

Rated Lamp Wattage	Lamp Spectrum	Lamp Diameter <i>inches</i>	Rated Voltage	Minimum Average Lamp Efficacy <i>lm/W</i>
40–205	Standard Spectrum	> 2.5	≥ 125 V	6.8*P ^{0.27}
			< 125 V	5.9*P ^{0.27}
		≤ 2.5	≥ 125 V	5.7*P ^{0.27}
			< 125 V	5.0*P ^{0.27}
40–205	Modified Spectrum	> 2.5	≥ 125 V ^g	5.8*P ^{0.27}
			< 125 V	5.0*P ^{0.27}
		≤ 2.5	≥ 125 V	4.9*P ^{0.27}
			< 125 V	4.2*P ^{0.27}

Note 1: P is equal to the rated lamp wattage, in watts.

Note 2: Standard Spectrum means any incandescent reflector lamp that does not meet the definition of modified spectrum in 430.2.

3.3.3.3 California Energy Commission

California’s Office of Administrative Law (OAL) enacts statewide regulatory programs published in the California Code of Regulations (CCR). CCR Title 20, Division 2, Chapter 4, Article 4, Section 1605.3 contains state regulations for IRLs in accordance with the Warren-Alquist State Energy Resources Conservation and Development Act, last revised in May 2012. This law requires that lighting standards be set to achieve a 50 percent reduction in energy consumption from 2007 levels for indoor residential lighting and a 25 percent reduction from 2007 levels for indoor commercial and outdoor lighting by 2018. Current CCR standards for IRLs are identical to EPL Act 1992 standards including the EISA 2007 exemptions.

CCR Title 24, Part 6 contains the 2013 Building Energy Efficiency Standards, Section 110.9 of which mandates requirements for lighting control devices and systems, ballasts, and luminaires. These regulations were approved in May 2012 and go into effect on January 1, 2014, replacing the 2008 Building Energy Efficiency Standards. The 2013 Building Energy Efficiency Standards are 25 percent more efficient than the previous standards for residential construction and 30 percent more efficient for non-residential construction.³ Products regulated by Title 24 include those that can be used with GSFLs and IRLs, such as automatic time-switch control devices, occupancy sensors, multilevel occupancy sensors, automatic daylighting control devices, interior photosensors, multilevel and outdoor astronomical time-switch controls, manual-on occupancy sensors, dimmers, integral current limiters, ballasts for residential recessed

^g Shown correctly in this table; erroneously written as “≤125 V” in the CFR. See the notice for further discussion.

luminaires, and dimming fluorescent ballasts. The regulations mandate that the products have specific features and capabilities in order to be installed.

3.3.3.4 Canadian Energy Efficiency Standards

The Natural Resources Canada (NRCan) Office of Energy Efficiency regulates the energy efficiency of GSFLs and IRLs in Canada.^h In 1992, the Canadian Parliament passed the Energy Efficiency Act (S.C. 1992, c. 36), which concerns minimum performance levels for energy-using products, effective February 1995. In November 1995, Canada's *Energy Efficiency Regulations* (SOR/94-651) were amended to include GSFLs and IRLs.

Canada's approach to the regulation of GSFLs closely resembles the U.S. federal efficiency standards established by EPA 1992 discussed in section 3.3.3.1. Though there are minor variations in definitions between the U.S. and Canadian standards, they effectively cover the same product. The Canadian minimum average CRI and lamp efficacy levels for GSFLs established in the 1995 amendments are identical to those shown in Table 3.3.1. In May 2010, NRCan published a bulletin proposing amendments to the regulations in order to modify GSFL definitions and to harmonize standards with the 2009 Lamps Rule, with the proposed amendments applying to those products manufactured on or after July 14, 2012. At the time of this analysis these proposed amendments had not been adopted.

Regarding IRLs, the 1995 amendments to SOR/94-651 included general service IRLs with minimum performance requirements consistent with EPA 1992. However, differing slightly from the U.S. approach, an amendment in April 2003 revised the regulations to include certain ER and BR IRLs. The current definition of "general service incandescent reflector lamp" in SOR/94-651 is as follows:

"general service incandescent reflector lamp" means an incandescent reflector lamp with a bulb shape as described in ANSI C79.1 or similar shape that has

- (a) an E26/24 single contact or E26/50 × 39 skirted, medium screw base,
- (b) a nominal voltage or voltage range that lies at least partially between 100 V and 130 V,
- (c) a diameter greater than 57 mm, and
- (d) a nominal power of not less than 40 W and not more than 205 W;
- but does not include
- (e) a coloured lamp,
- (f) a BR30 lamp or BR40 lamp with a nominal power of up to 50 W, or 65 W,
- (g) a R20 lamp with a nominal power of not more than 45 W,
- (h) a silver bowl lamp, or
- (i) a lamp for heat-sensitive applications⁴

In October 2011, NRCan published an amendment to the existing regulations to harmonize with EISA 2007; the amendment came into force April 12, 2012.

^h News and information on NRCan energy efficiency regulations and standards can be found at <http://oee.nrcan.gc.ca/regulations/7957>.

In April 2010, NRCan had proposed an amendment to harmonize with the 2009 Lamps Rule. NRCan's amendment was proposed to become effective July 14, 2012. In November 2011, NRCan revised the definition of IRLs in the April 2010 proposed amendment to match the definition ultimately published in the October 2011 amendment. At the time of this analysis this proposed amendment had not been adopted. The current Canadian regulations are shown in Table 3.3.5.

Table 3.3.5 Canadian Energy Efficiency Regulations for Incandescent Reflector Lamps

Rated Wattage <i>W</i>	Minimum Average Efficacy <i>lm/W</i>
ER30 or ER40 IRLs	
≤ 50	7.0
All Other Covered IRLs	
40-50	10.5
51-59	11.0
60-85	12.5
86-115	14.0
116-155	14.5
156-205	15.0

3.3.3.5 European Energy Efficiency Standards

Commission Regulation (EU) No 347/2010 (April 21, 2010) amended Commission Regulation (EC) No 245/2009 (March 18, 2009), which implemented Directive 2005/32/EC (July 6, 2005) of the European Parliament and the Council of the European Union and amended Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC (September 18, 2000) to establish a framework for setting energy efficiency requirements for energy-using equipment, including fluorescent lamps and the ballasts and luminaires that are used with these lamps. The energy efficiency requirements apply to equipment available on the market and do not differentiate requirements by lamp application. Lamps that are not white light sources, are directional, or intended for use in applications other than general lighting are exempted from standards. Additionally, the EU exempts lamps having:

- Six percent or more of total radiation of the range 250-780 nm in the range of 250-400 nm;
- Eleven percent of total radiation of the range 250-780 nm in the range of 630-780 nm;
- Five percent or more of total radiation of the range 250-780 nm in the range of 640-700 nm; and
- The peak of the radiation between 315-400 nm or 280-315 nm.

The EU also exempts double-capped fluorescent lamps having:

- A diameter of 7 mm (T2) and less;
- A diameter of 16 mm (T5) and lamp power $P \leq 13$ W or $P > 80$ W;

- A diameter of 38 mm (T12), lamp cap G-13 medium bipin (MBP) base, +/- 5 m color compensating filter value limit (cc). International Commission on Illumination coordinates $x = 0.330$, $y = 0.335$ and $x = 0.415$, $y = 0.377$; and
- A diameter of 38 mm (T12) and equipped with an external ignition strip.^{5 6}

The European energy efficiency requirements regulate the covered equipment in stages. First stage requirements began in 2010 and required double-capped fluorescent lamps of 16mm and 26mm (*i.e.*, T5 and T8 lamps) without integrated ballasts to comply with the efficacies listed in Table 3.3.6 at 25 °C. Second stage requirements begin in 2013, requiring double-capped fluorescent lamps of other diameters than those covered in the first stage to meet the minimum efficacy requirement for T8 lamps given in the first stage. Third stage requirements begin in 2018, requiring minimum compatible ballast efficiencies for all fluorescent lamps without an integrated ballast.

Table 3.3.6 EU Minimum Efficacy for T8 and T5 Fluorescent Lamps

T8 (26 mm Ø)		T5 (16 mm Ø) High Efficiency		T5 (16 mm Ø) High Output	
Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W) 100 h initial value	Nominal wattage (W)	Rated luminous efficacy (lm/W), 100 h initial value
15	63	14	86	24	73
18	75	21	90	39	79
25	76	28	93	49	88
30	80	35	94	54	82
36	93			80	77
38	87				
58	90				
70	89				

Source: 245/2009/EC

2010/347/EU amended the efficacy deductions given in 2009/245/EC for fluorescent lamps with high color temperature, high color rendering, second lamp envelope, or long life, so that required efficacy is cumulatively reduced as shown in Table 3.3.7.

Table 3.3.7 EU Deduction Percentages for Efficacy Values for Fluorescent Lamps

Lamp parameter	Deduction from luminous efficacy at 25 °C
$T_c \geq 5,000$ K	-10%
$95 \geq R_a > 90$	-20%
$R_a > 95$	-30%
Second lamp envelope	-10%
Lamp Survival Factor ≥ 0.50 after 40,000 burning hours	-5%

Source: 2010/347/EU

In addition to lamp efficacy, the EU standards contain requirements for lamp performance, including lamp lumen maintenance factor (LLMF) and lamp survival factor (LSF). The LLMF describes how bright a lamp remains as a percentage of the original brightness after a given period of time, while the LSF describes how long a lamp lasts before ceasing to function and requiring replacement, and is expressed as a percentage of the number of lamps still working

after a specified period of time. 2010/347/EU amended the LLMF and LSF requirements given in 2009/245/EC, and added cumulative LLMF deductions for certain lamps. Under current standards, for the first stage requirements, T5 and T8 lamps must have a minimum 80 CRI. For the second stage requirements, all covered fluorescent lamps without an integrated ballast must have a minimum CRI of 80, an LLMF as shown in Table 3.3.8 and Table 3.3.9, and an LSF as shown in Table 3.3.10.

Table 3.3.8 EU Lamp Lumen Maintenance Factors for Fluorescent Lamps

Table 6.10a - Lamp Lumen Maintenance Factors for Fluorescent Lamps					
Lamp lumen maintenance factor	Burning hours				
	Lamp types	2,000	4,000	8,000	16,000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts		0.95	0.92	0.90	--
T8 Double-Capped Fluorescent lamps on high frequency ballast with warmstart		0.96	0.92	0.91	0.90
Other Double-Capped Fluorescent lamps on high frequency ballast with warmstart		0.95	0.95	0.90	0.90
Circular Single-Capped Fluorescent lamps operating on non-high frequency ballasts, T8 U-shaped double-capped fluorescent lamps and spiral-shaped double-capped fluorescent lamps of all diameters equal to or larger than 16 mm (T5)		0.80	0.74	--	--
		0.72 at 5,000 burning hours			
Circular Single-Capped Fluorescent lamps operating on high frequency ballasts		0.85	0.83	0.80	--
		0.75 at 12,000 burning hours			
Other Single-Capped Fluorescent lamps operating on non-high frequency ballasts		0.85	0.78	0.75	--
Other Single-Capped Fluorescent lamps operating on high frequency ballast with warmstart		0.90	0.84	0.81	0.78

Source: 2010/347/EU

Table 3.3.9 EU Deduction Percentages for Fluorescent Lamp Lumen Maintenance Requirements

Lamp parameter	Deduction from lamp lumen maintenance requirement
Lamps with $95 \geq Ra > 90$	At burning hours $\leq 8,000$ h: -5% At burning hours $> 8,000$ h: -10%
Lamps with $Ra > 95$	At burning hours $\leq 4,000$ h: -10% At burning hours $> 4,000$ h: -15%
Lamps with a colour temperature $\geq 5,000$ K	-10%

Source: 2010/347/EU

Table 3.3.10 EU Lamp Survival Factors for Fluorescent Lamps

Lamp survival factor	Burning hours			
	2,000	4,000	8,000	16,000
Lamp types				
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0.99	0.97	0.90	--
Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0.99	0.97	0.92	0.90
Circular Single-Capped Fluorescent lamps operating on non-high frequency ballasts, T8 U-shaped double-capped fluorescent lamps and spiral-shaped double-capped fluorescent lamps of all diameters equal to or larger than 16 mm (T5)	0.98	0.77	--	--
	0.50 at 5,000 burning hours			
Circular Single-Capped Fluorescent lamps operating on high frequency ballasts	0.99	0.97	0.85	--
	0.50 at 12,000 burning hours			
Other Single-Capped Fluorescent lamps operating on non-high frequency ballasts	0.98	0.90	0.50	--
Other Single-Capped Fluorescent lamps on high frequency ballast with warmstart	0.99	0.98	0.88	--

Source: 2010/347/EU

3.3.4 Non-Regulatory Initiatives

DOE reviewed several national, regional, and local voluntary programs that promote the use of energy efficient lighting in the United States. The following section summarizes these programs for the lamps covered by this rulemaking. While it is not an exhaustive list, the discussion provides detail on some notable initiatives that characterize recent developments in the lighting market.

3.3.4.1 Federal Energy Management Program

The Federal Energy Management Program (FEMP) helps federal buyers identify and purchase energy efficient products including certain GSFLs. Section 161 of EPCA 1992 encourages energy efficient federal procurement. Executive Order 12902 and FAR section 23.704 direct agencies to purchase products in the upper 25 percent of energy efficiency. FEMP typically provides recommendations of total light output (in lumens) and the best available models of fluorescent lamps. However, at the time of publishing, FEMP has temporarily suspended its energy efficiency requirements for fluorescent lamps as it evaluates the market impact of the standards adopted by the 2009 Lamps Rule (hereafter “the July 2012 standards”). The program will issue updated energy efficiency requirements when the GSFL market distribution stabilizes. FEMP continues to offer buyer support tools, such as efficiency guidelines, cost-effectiveness examples, and a cost calculator. FEMP also offers training, on-site audits, demonstrations, and design assistance.⁷

3.3.4.2 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) has both a Residential Lighting Initiative and a High Performance Commercial Lighting Initiative. The Residential Lighting Initiative primarily promotes high efficiency fixtures and CFLs, neither of which are covered under this rulemaking. The purpose of CEE’s High Performance Commercial Lighting Initiative is to define what constitutes “high performance,” and the initial efforts have focused on efficient T8

fluorescent lighting products. On May 1, 2007, CEE updated its specification for high performance T8 lamps as a T8 lamp not greater than 32 W, with minimum initial lamp lumens of 3,100 lumens or greater.⁸ On July 29, 2013, CEE released its specificationⁱ for 25 W and 28 W T8 lamps. CCE specifies 28 W T8 lamps under 4500 K and over 4500 K to have a minimum initial lumen output of 2585 and 2480 lumens respectively. CCE specifies 25 W T8 lamps under and over 4500 K to have a minimum initial lumen output of 2400 and 2300 respectively. CEE also provides a database of detailed information on over 160 utilities and efficiency program administrators that offer prescriptive incentives towards the purchase of high efficiency commercial lighting products. The information was compiled in April 2011 and includes information on measures specifically involving fluorescent lamps and ballasts, fluorescent fixtures, other lighting technologies, and lighting controls.⁹

3.3.4.3 Energy Efficient Commercial Building Deduction

The Energy Policy Act of 2005 (Pub. L. 109-58; EAct 2005) created the Energy Efficient Commercial Buildings Deduction (26 U.S.C 179D), which establishes a tax deduction for building owners who incur expenses for energy efficiency upgrades. Originally effective for property in service from January 1, 2006 through December 31, 2008, the measure allows partial deductions for improvement in interior lighting. Projects must be certified to reduce total annual energy and power costs solely through changes to the building's lighting, HVAC/hot water, and building envelope to at least 50 percent less than a reference building satisfying the requirements of ASHRAE/IESNA 90.1-2001, or to at least 10-20 percent less energy consumption through lighting alone. Though the statute does not specify required lamp types or efficacies, it does call for an overall reduction in lighting power density. The Emergency Economic Stabilization Act of 2008 (HR-1424), approved and signed on October 3, 2008, extends the benefits of EAct 2005 through December 31, 2013.

3.3.4.4 Efficiency Vermont

In Vermont, agricultural operations and businesses are eligible for prescriptive and customized incentives on products proven to help make them more efficient. Efficiency Vermont gives prescriptive rebates for a variety of equipment and for lighting products. Efficiency Vermont's Agricultural Rebate Program will rebate \$60 to \$120 per T12 fluorescent fixture replaced with a high performance T8 fluorescent fixture, or a T5 HO fluorescent fixture. Replacement fixtures must be vapor proof, use electronic ballasts, and bulb-ballast combinations must be listed with the CEE.¹⁰ Similarly, Efficiency Vermont offers businesses rebates from \$10 to \$75 for each T12 fixture replaced with a high performance T8 or T5 system. This version of the rebate expires at the end of 2013.¹¹

3.3.4.5 Pacific Gas and Electric Company Rebates

The Pacific Gas and Electric Company (PG&E) offers rebates and other incentives to businesses and non-residential customers to increase their energy efficiency, including use of high performance GSFLs. All products must meet program requirements listed on the PG&E program web site or application forms. Owners or managers can receive rebates of \$17.50 to

ⁱ This specification is available at:

http://library.cee1.org/sites/default/files/library/5696/CEE_ComLit_RW_Lighting_Spec_July2013.pdf

\$20.00 per T8 or T5 fluorescent lamp-and-ballast fixture or retrofit kit. PG&E will also give rebates of \$0.50 or \$1.00 per 32 W T8 lamp replaced by either a 28 W T8 or 25 W T8, respectively.¹² These rebates expire December 31, 2014.

3.3.4.6 Roseville Electric

Roseville Electric is a Californian utility that offers a rebate program to any Roseville Electric business account. With regard to lighting, the program seeks to increase installation of high performance lighting products which will improve work performance and lower facilities' energy costs. In order for fluorescent lamps to qualify for these rebates, the lamps must be certified by CEE. Roseville Electric offers a \$9 rebate per T8 fluorescent lamp that is replaced with a 25 W or 28 W T8. Delamping rebates range from \$8 to \$26 per fluorescent lamp removed depending on the length. Lamp removal may only be done with qualifying lamp-and-ballast retrofits. The program will expire on June 30, 2014 or once the funds are exhausted.¹³

3.3.4.7 Con Edison

In New York, ConEd runs a Multi-Family Energy Program with rebates for energy efficiency improvements. Owners and managers of multi-family buildings (of 5 to 75 units in size) are eligible for the program. Offers include not only rebates, but also free surveys to evaluate potential energy-saving upgrades as well as free installation inside individual units. The rebates for linear fluorescent fixtures range from \$65 per one-lamp fixture up to \$80 per four-lamp fixture. Furthermore, ConEd offers up to 50 percent of the full replacement incentive for relamp and rebalasting. There are no expiration dates for these rebates at this time.¹⁴

3.3.4.8 APS Rebate Programs

In Arizona, APS offers a number of incentives and rebate programs. Solutions for Business offers incentives that help businesses increase energy efficiency and reduce energy use. APS non-residential customers (including schools, small businesses, industrial facilities and public agencies) can choose energy efficiency measures with rebates for existing buildings and new construction. For this program, APS provides a rebate for T8 and T5 fluorescent lamps and electronic ballasts for \$5 to \$12 per lamp-and-ballast system depending on the lamp diameter and length. APS also offers a rebate of \$4 per T8 lamp replaced with a premium T8 lamp. These programs expire at the end of 2013, but they are expected to be renewed pending Commission approval.¹⁵

3.3.4.9 Cape Light Compact – Commercial, Industrial and Municipal Buildings Energy Efficiency Rebate Program

Through a multi-member partnership, Cape Light Compact (CLC) and MassSave offer a variety of financial incentives for commercial, industrial, and municipal facilities in Massachusetts. Custom rebate options are available for both new construction and retrofit measures in commercial/industrial buildings, as well as for small businesses and municipal projects. There are prescriptive rebates through the partnership on sensors and fluorescent lighting products and controls for eligible new and existing buildings. Rebates vary depending on whether projects are retrofit or new construction. Through this program, CLC offers \$15 to \$75 per fluorescent fixture in retrofits. For new construction projects the CLC provides rebates of \$10 to \$35 per high efficiency fluorescent system and through its Performance Lighting incentive

up to \$1.00 per watt saved above the state energy code. This program expires October 31, 2015.¹⁶

3.3.4.10 Central Electric Cooperative – Non-Residential Lighting Rebate

In Oregon, the Central Electric Cooperative offers a commercial lighting system improvement incentive for any customer not on a residential utility rate. For existing building projects, the Central Electric Cooperative will give rebates of \$10 to \$65 per T12 fluorescent lamp-and-ballast replaced with a T5 or T8 fluorescent lamp-and-ballast, \$120 to \$180 per high bay fixture of other lighting technology (*e.g.*, mercury vapor, high pressure sodium, metal halide, incandescent) replaced with a T8 or T5 fluorescent high bay fixture, and \$50 to \$100 per T12 fluorescent lamp-and-ballast replaced with a T5 fluorescent lamp-and-ballast. The organization also offers rebates of \$10 to upgrade a fixture to a high performance T8 fixture, a \$50 rebate for HO T8 or T5 fixtures, and a \$30 rebate for sensor or timer controlled fluorescents. The Central Electric Cooperative will give a six-month notice of alterations to the program.¹⁷

3.3.4.11 Empire – Commercial and Industrial Energy Efficiency Rebates

The Empire District Electric Company (Empire) offers a Commercial/Industrial Prescriptive Rebate Program to its non-residential customers in Arkansas who purchase certain high efficiency products for eligible facilities. A variety of prescriptive rebates are available to customers served under any non-residential rate schedule in the Empire service territory. The rebates, which can be applied to both new construction and retrofit projects, are offered for certain products meeting the program's energy efficiency standards. Empire offers a rebate of \$5 to \$8 per fluorescent lamp-and-ballast system, \$9 to \$18 per high performance T8 fluorescent lamp system, \$0.50 per 28 W or less T8, \$40 to \$125 per high bay fluorescent lamp-and-ballast system, \$16 to \$24 per pendant, wall mount, or recessed indirect fixture, and \$12 to \$16 per fluorescent lamp fixture with specular reflectors and a reflectivity of at least 87 percent. There are no expiration dates for these rebates at this time.¹⁸

3.3.5 Historical Shipments

Shipment data and market trend information are used to conduct the shipment analysis and develop base-case forecasts in the shipment analysis (see chapter 11 of this NOPR TSD). DOE also uses shipment data to identify and analyze representative product classes and lamps to ensure the analysis is representative of the market (see chapter 5 of this NOPR TSD). Shipment data also feeds into the national impact analysis (see chapter 12 of this NOPR TSD). Based on its understanding of trends in the market, DOE estimated how the market would respond to the various ELs. The following section outlines the publicly available historical data and trends for GSFLs and IRLs. For the 2009 Lamps Rule, NEMA provided historical shipments of GSFLs and IRLs from 2001 to 2005 in a public comment,¹⁹ and for this rulemaking, NEMA provided GSFL and IRL historical shipments for 2006 through 2011 to DOE upon request.

3.3.5.1 GSFL Shipments

For GSFLs, the historical shipment data is broken down by lamp length (2-foot, 4-foot, and 8-foot), diameter (T12, T8, and T5), shape (linear and U-shaped), and in some cases, lumen output (SO or HO). Four-foot MBP lamps have consistently constituted the vast majority of GSFL sales. These have been followed, in order of unit sales, by 8-foot SP slimline lamps, then

8-foot RDC HO lamps, with shipments of 2-foot U-shaped lamps consistently making up the smallest portion (less than five percent) of unit sales. After 2005, 8-foot RDC HO lamp shipments declined to less than five percent as well, nearly equaling 2-foot U-shaped lamp shipments. For this rulemaking, NEMA provided DOE with combined shipment data for 4-foot T5 MiniBP SO and HO lamps from 2006 through 2011, showing an increasing share of unit sales that reached a little over eight percent of shipments in 2011.

GSFLs in the categories of 4-foot MBP, 8-foot SP slimline, 8-foot RDC HO, 2-foot U-shaped, and T5 SO and HO lamps are primarily used in the commercial and industrial sectors. As Table 3.3.11 shows, 4-foot MBP fluorescent lamp shipments show a clear decrease in the T12 market share and an increase in the T8 market share. These shipments, coupled with information obtained from NEMA and feedback from interviews with manufacturers, suggest that consumers are moving away from 4-foot T12 fluorescent lamps and toward 4-foot T8 fluorescent lamps. This trend is reflected both in the popularity of T8 lamps in new construction and in lighting system retrofits and renovations where the ballast is replaced. The vast majority of ballasts are electronic, with instant start (IS) technology composing about 85 to 90 percent of the market. The decline of 4-foot T12 shipments was compounded by energy conservation standards for T12 fluorescent ballasts, requiring compliance in 2009 and 2010. (See 10 CFR 430.32(m)(4)(ii) and 430.32(m)(5)-(6))

Table 3.3.11 NEMA Shipments of Four-Foot Medium Bipin GSFLs

		T12 4-Foot MBP	T8 4-Foot MBP	Total 4-Foot MBP
Unit Sales by Year <i>thousands</i>	2001	212,564	164,129	376,593
	2002	205,998	163,632	369,630
	2003	181,931	172,294	354,225
	2004	175,850	195,698	371,548
	2005	162,664	215,530	378,194
	2006	150,522	230,988	381,510
	2007	131,584	247,331	378,915
	2008	115,064	253,705	368,769
	2009	111,500	219,101	330,601
	2010	103,300	233,798	337,098
	2011	92,588	265,889	358,477

As Table 3.3.12 shows, historical shipments of 8-foot SP slimline GSFLs reflect a decline in shipments of T12 lamps through 2009, but not an increased market share in T8 lamps that compensates for this decrease. There was a brief increase in shipments of 8-foot SP slimline lamps in 2010, however, shipments began to show a decrease again in 2011. Manufacturer feedback indicated that a portion of the 8-foot T12 market is being transferred to the 4-foot T8 market as two 8-foot T12 lamps can be replaced by four 4-foot T8 lamps.

Table 3.3.12 NEMA Shipments of Eight-Foot Single Pin Slimline GSFLs

		T12 8-Foot SP Slimline	T8 8-Foot SP Slimline	Total 8-Foot SP Slimline
Unit Sales by Year <i>thousands</i>	2001	43,265	4,405	47,670
	2002	41,443	5,300	46,743
	2003	37,170	5,183	42,353
	2004	36,263	5,727	41,990
	2005	33,636	5,176	38,812
	2006	27,030	5,721	32,751
	2007	25,400	4,718	30,118
	2008	22,208	4,480	26,688
	2009	20,944	4,902	25,846
	2010	30,396	5,112	35,508
	2011	26,210	4,306	30,516

Table 3.3.13 shows the historical shipments of 2-foot U-shaped GSFLs. While U-shaped T12 lamp shipments are declining, no clear trend can be seen in the market share progression of U-shaped T8 lamps. Nonetheless, the market share of U-shaped lamps has remained small compared to that of 4-foot MBP and 8-foot SP slimline lamps.

Table 3.3.13 NEMA Shipments of Two-Foot U-Shaped GSFLs

		T12 2-Foot U-Shaped	T8 2-Foot U-Shaped	Total 2-Foot U-Shaped
Unit Sales by Year <i>thousands</i>	2001	9,672	8,014	17,686
	2002	9,314	6,784	16,098
	2003	9,460	7,018	16,478
	2004	7,014	9,224	16,238
	2005	8,839	8,659	17,496
	2006	5,803	12,086	17,889
	2007	5,169	11,502	16,671
	2008	4,626	9,382	14,008
	2009	3,882	8,455	12,337
	2010	3,683	8,786	12,469
	2011	3,574	9,012	12,586

While 4-foot MBP, 8-foot SP slimline, and 2-foot U-shaped lamps are primarily used in the commercial sector, 8-foot RDC HO lamps are primarily used in the industrial sector for applications such as high bay lighting. Table 3.3.14 shows the historical shipments of 8-foot RDC HO lamps. The market share of 8-foot RDC HO is relatively small compared to that of 4-foot MBP and 8-foot SP slimline lamps. As seen in NEMA's historical shipment data, T12 8-foot RDC HO lamps had the majority of the RDC HO market. After 2005, NEMA reported T12 and T8 8-foot RDC HO data as combined totals for disclosure purposes. Discussions with manufacturers indicate that they expect any migration of the 8-foot RDC HO market to go toward T5 HO lamps.

Table 3.3.14 NEMA Shipments of Eight-Foot Recessed Double Contact High Output GSFLs

		T12 8-Foot RDC HO	T8 8-Foot RDC HO	Total 8-Foot RDC HO
Unit Sales by Year <i>thousands</i>	2001	23,887	691	24,578
	2002	24,398	647	25,045
	2003	24,206	467	24,673
	2004	24,591	674	25,265
	2005	25,442	420	25,862
	2006	--	--	18,828
	2007	--	--	19,741
	2008	--	--	18,575
	2009	--	--	15,799
	2010	--	--	15,408
	2011	--	--	15,286

Table 3.3.15 shows NEMA's 2006 through 2011 combined HO and SO 4-foot T5 MiniBP lamp shipments. While 4-foot MBP lamps have always held the definitive majority of the market, 4-foot T5 MiniBP lamps are gaining an increasing market share and have become the next most prevalent lamp type, surpassing 8-foot SP slimline lamps in 2011. Still less than 10 percent of the market, 4-foot T5 MiniBP shipments (according to manufacturer interviews, specifically T5 HO shipments) have grown due to commercial applications using the higher efficacy lamps and industrial high bay applications switching from less-controllable technologies (e.g., high-intensity discharge [HID] lamps). Additionally, the increase of 4-foot T5 MiniBP shipments has also been influenced by non-regulatory incentives such as utility rebates. Several programs offer rebates to commercial, non-residential, and multi-family customers for the installation of T5 lamps in both new construction and renovation applications (see section 3.3.4 for examples). As mentioned previously, 4-foot T5 MiniBP HOs are also expected to capture a portion of the 8-foot RDC HO market.

Table 3.3.15 NEMA Shipments of Four-Foot T5 Miniature Bipin Standard Output and High Output GSFLs

		Total 4-Foot T5 MiniBP SO and HO
Unit Sales by Year <i>thousands</i>	2006	21,465
	2007	26,318
	2008	28,784
	2009	24,815
	2010	32,508
	2011	37,930

3.3.5.2 IRL Shipments

As Table 3.3.16 shows, both halogen and non-halogen IRL shipments have been declining since 2006. However, the halogen reflector lamp types are generally maintaining their percentage of total shipments.

Table 3.3.16 NEMA Shipments of IRLs

		PAR Incandescent	R Incandescent	PAR 38 Halogen	PAR 30 and PAR 20 Halogen	Total IRLs
Unit Sales by Year <i>thousands</i>	2001	8,900	89,465	40,804	32,523	171,692
	2002	6,697	96,218	45,938	27,128	175,961
	2003	5,090	103,407	45,673	30,506	184,676
	2004	5,308	111,720	49,937	35,567	202,532
	2005	15,018	124,641	46,329	39,985	225,973
	2006	4,800	121,308	43,265	36,054	205,427
	2007	3,658	114,521	40,377	36,390	194,946
	2008	3,228	99,446	36,209	34,320	173,203
	2009	2,237	89,288	39,039	30,483	161,047
	2010	2,778	86,681	36,106	30,872	156,437
	2011	2,100	85,293	35,372	27,815	150,580

3.4 TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a list of technologies that could be used to improve the efficacy of GSFLs and IRLs. The following assessment provides a description of the basic construction and operation of GSFLs and IRLs, followed by technology options to improve efficacy.

3.4.1 Basic Structure and Operation of General Service Fluorescent Lamps

The fluorescent lamp is a low pressure gas discharge source. The lamp consists of a glass bulb or tube, filled with low pressure mercury vapor and inert gas, with electrodes sealed onto both ends of the tube. Once voltage is applied, the electrodes emit large quantities of electrons that then collide with gaseous mercury atoms, exciting electrons within those atoms. As the electrons decay to their stable or ground state, they emit ultraviolet (UV) radiation. The phosphors coating the bulb's inner wall then absorb this UV radiation and emit light in the visible spectrum. The fluorescent lamp has five major components in its construction: bulb, electrodes, base, gas fill, and phosphors.

Two electrodes are hermetically sealed to both ends of the bulb. The electrodes are usually constructed from coiled tungsten wires coated with a mixture of alkaline oxides. A base provides an electrical connection to these electrodes and also supports the lamp. Depending on the start method and operational properties of the lamp (*e.g.*, dimming, wattage), lamp designs may use different bases such as SP, MBP, MiniBP, and RDC. Once voltage is applied to the electrodes, the tungsten coil and coatings emit large quantities of electrons when the coating is at the proper temperature (1,000–1,300 K). These electrons then collide with gaseous mercury

atoms, exciting electrons within those atoms. As the electrons decay to their stable or ground state, they emit UV radiation primarily at 254 nanometers (nm). In addition to the mercury vapor, an inert gas or a combination of gases is added to the lamp primarily to moderate the collisions of mercury ions and minimize evaporation of the electrode coating. As discussed above, the UV radiation is then absorbed by the phosphors and reemitted as light.

A fluorescent lamp must be operated in series with a current-limiting device, which is usually a magnetic or electronic ballast. The 2011 Ballast Rule set standards difficult for magnetic ballasts to meet (76 FR 70548 [Nov. 14, 2011]); while electronic ballasts, the more efficient technology, will be able to meet standards. While this rulemaking covers only the fluorescent lamp, it does evaluate the lamp-and-ballast system when evaluating energy savings of a particular GSFL efficacy level.

In addition to limiting current, ballasts also supply starting and operating voltages required by the lamp. Some ballasts also preheat the electrodes before initiating the arc. Electronic ballasts can use a variety of starting methods, including IS, rapid start (RS), and programmed start (PS).^j RS ballasts heat the electrodes for a limited time before lamp ignition which leads to a longer lamp life than an IS ballast. However, RS ballasts have difficulty complying with standards set in the 2011 Ballast Rule. 76 FR 70548 (Nov. 14, 2011). PS ballasts, like RS, heat the lamp filaments before igniting the lamp and some remove all power to the electrodes after ignition (*i.e.*, cathode cut-out) resulting in more energy savings compared to RS ballasts. IS ballasts apply a higher voltage to initiate the lamp ignition rather than applying a steady filament voltage.

Because different starting methods result in changes in lamp efficacy DOE considers different starting methods in its analysis. For example, DOE pairs 4-foot T8 MBP lamps with electronic, IS ballasts and electronic, PS ballasts. Electronic ballasts are also available in a variety of lamp-per-ballast designs. For example, electronic ballasts are typically manufactured in 1-, 2-, 3-, 4- and 6-lamp versions. In its analysis for this rulemaking, DOE is focusing on the more prevalent 2- and 4-lamp systems.

Some of the performance parameters used to characterize a ballast include ballast factor (BF), ballast luminous efficiency (BLE), and power factor. Each ballast has a BF, which is the output of the ballast delivered to a reference lamp in terms of power or light divided by the output of the relevant reference ballast delivered to the same lamp (ANSI C82.13-2002). To calculate the light output of a lamp-and-ballast system, one would multiply the light output of the lamp by both the number of lamps operated by the ballast and its BF. BLE, a new metric for fluorescent lamp ballasts, means the total lamp arc power divided by the ballast input power multiplied by the appropriate frequency adjustment factor. BLE describes the percentage of ballast input power that is used by the lamp to produce light. The power factor is calculated by determining the ratio of the active power to the apparent power.

^j Programmed start ballasts delay the starting voltage until the electrodes are heated to an optimum temperature. Then, they may reduce the voltage on the electrodes.

Fluorescent lamp bulbs can be manufactured in a variety of shapes and sizes. The GSFLs in this rulemaking include 4-foot and 8-foot linear lamps and 2-foot U-shaped lamps. Changing the shape of the lamp can alter the overall efficacy as the lamp may require a different voltage to maintain the discharge and UV radiation. In addition, the length of a lamp also influences its efficacy. As Figure 3.4.1 shows, the greater the length, the higher the efficacy, since losses associated with the electrodes are essentially constant. Therefore, a longer arc length will have less electrode power losses relative to the total losses. However, because different lamp shapes and lengths may provide different utility to the consumer and also depend on the fixture, DOE is not proposing these properties as technology options. Rather, as indicated in the discussion of product classes in section 3.5.1, product classes differentiate lamps by their shape and length. In its analysis, DOE was unable to determine if base type alone impacts efficacy and therefore did not propose this as a technology option.

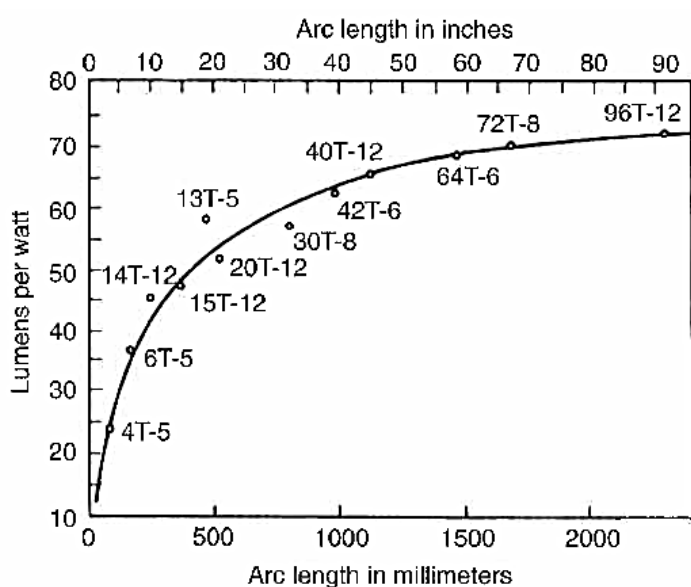


Figure 3.4.1 Lamp Length Effects on Efficacy

Source: IESNA Lighting Handbook: Reference & Application²⁰

3.4.2 GSFL Technology Options

This section outlines the technology options DOE is proposing for improving efficacy of GSFLs. In discussing each of the following technology options, it is important to note that the efficacy of a lamp, in terms of lumens per watt (lm/W), can be affected in two major ways. One method is by affecting the total light output at a given wattage. This generally refers to changing the spectral output of the lamp to result in a larger overlap with the spectral eye sensitivity.^k The second method of changing lamp efficacy is requiring a different electrical wattage input to maintain a given lumen output. This method involves tweaking the processes that convert electrical energy to visible radiation.

^k A “lumen” is a measurement of the radiometric energy emission from a light source weighted by the response function of a human eye, called the photopic spectral luminous efficiency function, $V(\lambda)$. See Figure 3.4.4 for a graph of this function.

3.4.2.1 Highly Emissive Electrode Coatings

Fluorescent lamp electrodes are generally tungsten filaments coated with a mixture of alkaline earth oxides. The purpose of the electrodes is to emit a sufficient number of electrons to ionize the gas and maintain the lamp discharge. When electrons are more easily emitted from the electrodes, a lower voltage is needed to maintain the arc. Therefore, any improvement in electrode coating that would allow electrons to be more easily removed from the electrodes would reduce the lamp power and increase the overall efficacy of the lamp. This technology option essentially addresses the efficiency of the conversion of electrical input power to visible radiation. In addition to raising efficacy, the electrode coatings can result in an increased lamp lifetime. Without sufficient electron emission from the electrode, a large voltage gradient is created in front of the electrode during the cathode cycle, which is emitting negatively charged ions and receiving positively charged ions. This high electric field accelerates these ions into the electrode at a high velocity, causing electrode damage. The damage shortens the lifetime of the lamp. Conventional emissive coatings include barium oxide (BaO), calcium oxide (CaO), and strontium oxide (SrO). Additional materials have been mixed with existing conventional oxides to coat fluorescent lamp electrodes. These materials include zirconium oxide (ZrO), which extends lamp lifetime, and silicon carbide (SiC), which more effectively removes electrons from the electrode.

3.4.2.2 Higher Efficiency Lamp Fill Gas Composition

Fluorescent lamps contain mercury vapor, which when ionized produces UV radiation. They also contain a rare gas or combination of gases to facilitate ignition. These “lamp fill gases” affect the mobility of the mercury ions and electrons in the lamp plasma based on their molecular weight. Lower molecular weight gases generally result in higher lamp efficacy. As lighter gases are used, the mobility of mercury ions and electrons increases, allowing them to reach greater velocities. This causes a rise in electron temperature of the plasma, facilitating recombination and ultimately raising the UV radiation to saturation level. However, if the mobility of the ions and electrons exceeds a certain optimal point, they are then able to reach the lamp glass surface, which prevents emission and effectively reduces UV output.

Standard lamps generally use argon gas. Energy-saver lamps may use a mixture of krypton and argon. In addition, neon and xenon are sometimes blended with argon. As Figure 3.4.2 shows, given a linear power density of 25 watts/foot (W/ft), both neon and argon result in similar UV radiation. However, given a high linear power density of 50 W/ft, neon clearly allows for higher UV radiation, and therefore higher efficacy.

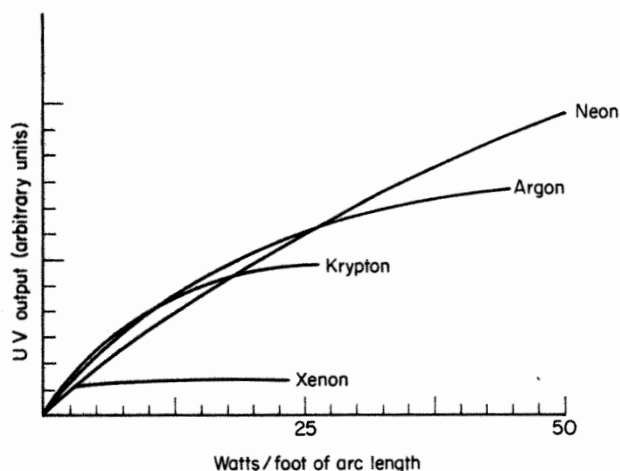


Figure 3.4.2 Lamp Fill Gas Effect on UV Output for T12 Lamps

Source: Electric Discharge Lamps²¹

These gases are usually at low pressures, ranging from 100 to 400 Pascals. As the pressure exceeds a certain point, elastic scattering increases, decreasing the mobility of the ions and electrons. This decreased mobility lowers the total UV radiation of the lamp, thereby decreasing lamp efficacy. Because fluorescent lamp ballasts are often current-controlled devices, the use of higher efficiency lamp fill gases, such as krypton, results in lower power. DOE research and interviews with manufacturers have indicated that these lower power lamps, often called energy-saver lamps or reduced wattage lamps, have some restrictions on usage. Manufacturer feedback has indicated that any amount of krypton in reduced wattage lamps causes issues with lamp starting and striations in cold temperature applications below 60-65 °F. Feedback from manufacturers in interviews also indicated that problems encountered with dimming linear fluorescent lamps, including lamp starting, striations, and dropout, are exacerbated by the use of krypton in reduced wattage lamps. However, krypton is not the only factor causing these issues with reliably dimming reduced wattage lamps. The ballast, compatibility with the dimmer and lamp itself, and the environment in which dimming is being utilized can also be factors in reliably dimming a lamp.

Lamp fill gas composition can also affect lamp lifetime due to collisions between the lamp fill gas and the evaporated electrode coatings. As discussed earlier, one common emissive coating used on electrodes is barium oxide (BaO). During lamp operation the BaO coating slowly evaporates from the surface of the electrode. However, some of these escaped barium atoms then collide with the lamp fill gas, propelling them back toward the electrode and redepositing them. As Figure 3.4.3 shows, the relative thermionic emission for the cathode, a measure of the number of electrons emitted, is much greater for a larger molecular weight gas, such as krypton, than for a lighter gas, such as neon. This is because a larger mass atom can more effectively collide with and change the trajectory of the barium atoms, providing a lower diffusion rate of the barium atoms away from the electrode. This redeposition of the electrode coating results in a longer lamp lifetime as less of the electron emissive material is lost.

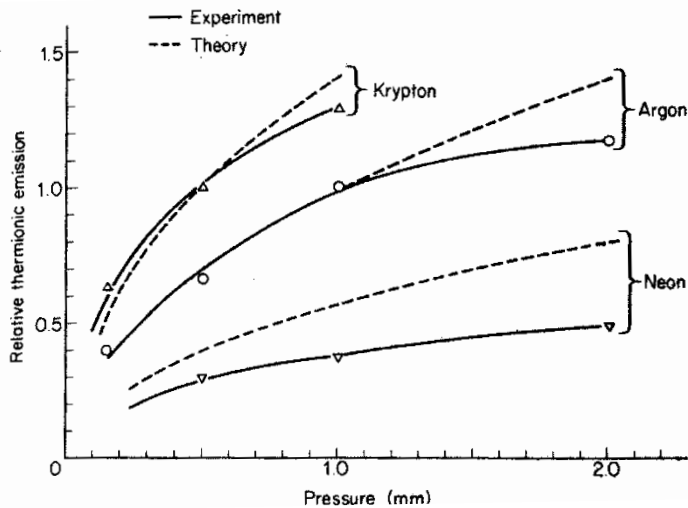


Figure 3.4.3 Lamp Fill Gas Effect on Thermionic Emission for T12 Lamps

Source: Electric Discharge Lamps²²

3.4.2.3 Higher Efficiency Phosphors

As described earlier, the main purpose of phosphor in a fluorescent lamp is to absorb the UV radiation and reemit it as visible radiation. Therefore, one method of improving lamp efficacy is to increase phosphor efficiency. The two groupings of phosphors used in fluorescent lamps are halophosphors and triband phosphors, the latter of which contain rare earth elements. Initially, halophosphors, typically composed of group 17 elements from the periodic table of elements, were predominantly used in fluorescent lamps. Then, in the late 1980s, rare earth phosphors, which are generally considered to have higher phosphor efficiencies, better color rendering properties, and improved lumen maintenance, were integrated into the lamps. Specifically, these narrow-band rare earth phosphors (containing the rare earth elements terbium, europium, and yttrium), emit light in the short, middle, and long wavelength ranges of the visible spectrum. Lamps that meet the July 2012 standards predominately use triband phosphors, which include rare earth phosphors.²³ However, the more efficient fluorescent lamps on the market today exclusively use triband phosphors.

Therefore, lamp efficacy can be improved by using triband phosphors, which can increase UV absorption and emission of radiation in the visible spectrum relative to other phosphors. Typically, there are efficiency losses in the phosphor's conversion of UV radiation to visible radiation, or light. Some of these losses are related to the extent to which the phosphors emit light in the visible spectrum (*i.e.*, radiation with wavelengths between 400 and 750 nm) and the extent that they radiate at visually sensitive wavelengths. Triband phosphors allow a lamp to emit light at the wavelengths to which human eyes are most sensitive which increases lamp efficacy. To understand this effect it is important to note the relationship between the efficiency losses in the phosphor's conversion of light, wavelengths sensitive to the human eye, and measurement of lamp efficacy.

Lumens, used to calculate lamp efficacy, measure the radiometric energy emission from a light source weighted by the response function of the human eye, $V(\lambda)$ (also referred to as the

photopic luminous efficiency function). Figure 3.4.4 depicts $V(\lambda)$. The human eye does not have the same level of sensitivity to all wavelengths of light. For example, the eye is highly sensitive to light emission around 550 nm, but less sensitive to emission at 450 nm or 650 nm.

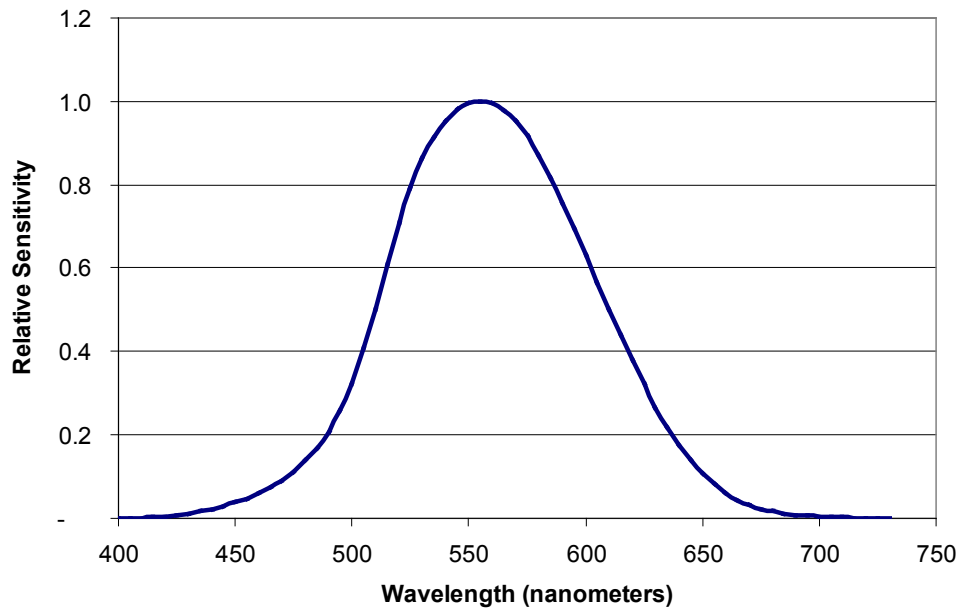


Figure 3.4.4 Human Eye Photopic Spectral Luminous Efficiency Function, $V(\lambda)$

Therefore, the specific wavelengths that a lamp emits will affect the lamp's calculated efficacy. In other words, because the human eye is less responsive to certain wavelengths of light, such as those in the blue spectrum, those lamps that contain these less sensitive wavelengths will have lower efficacies. As such, every watt of radiometric energy emitted from a fluorescent lamp is not equal under a lm/W metric. Therefore, by allowing a lamp to emit greater light at wavelengths to which the human eye is more sensitive, triband phosphors are able to increase lamp efficacy.

Lamp efficacy can also be improved by increasing the thickness of the phosphor layer, also called phosphor weight. Generally, as phosphor thickness increases, lamp light output increases until it slightly decreases or stays flat. Figure 3.4.5 illustrates this point, where coating weight is indicative of phosphor thickness.

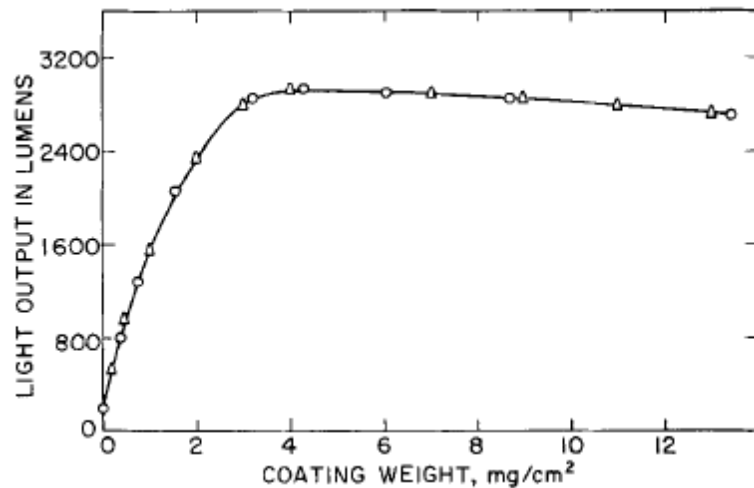


Figure 3.4.5 Light Output versus Phosphor Thickness

Source: Journal of the Electrochemical Society²⁴

Different types of phosphor emit light with different spectral power distributions (SPDs), and the choice of phosphor or blend of phosphors greatly affects the color of the lamp. The SPD of light emitted from a lamp characterizes the amount of power radiated at each wavelength in the visible spectrum. Figure 3.4.6 illustrates a sample SPD. It is apparent that the light source emits more radiation at certain wavelengths than others.

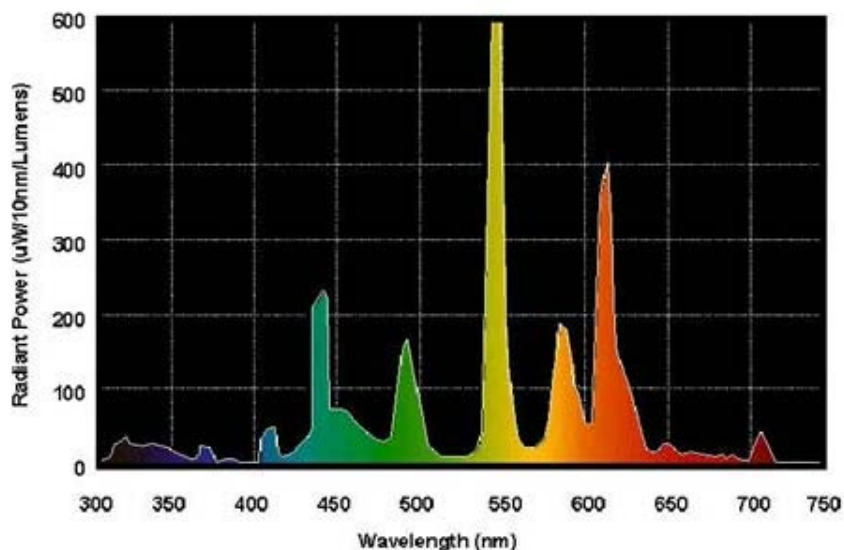


Figure 3.4.6 Sample Power Spectrum Distribution

Source: www.gelighting.com²⁵

This SPD determines the correlated color temperature (CCT) and the CRI, both important properties for measuring the color quality of light. CRI, a single value with no units, is a measure of the color rendering properties of a light source, or the ability of a light source to show the

“true” color of an object as compared to a reference source.^{1 26} The maximum CRI is 100. Lower CRI values indicate greater variation in an object’s apparent color compared to when lit by the reference source. DOE has observed that higher efficiency phosphors on the market typically offer higher CRIs. While CRI is not necessarily positively correlated to efficacy, the majority of phosphors offered in the market currently reflect this relationship. Typically lamps with a CRI in the 60s use only less efficient halophosphors, while lamps with a CRI in the 70s (700-series phosphor) and in the 80s (800-series phosphor) use more efficient rare earth phosphors. In fact, DOE research indicates that fluorescent lamp nomenclature represents color by a three digit number (e.g. 735 or 835) beginning with the first digit of the lamp’s CRI (e.g. 7 or 8) followed by the first two digits of the lamp’s CCT.^m Currently, the majority of lamps compliant with the July 2012 standards are 800 series.

CCT, a single value with units of degrees Kelvin (K), is a measure of the color appearance of light emitted from a lamp.^{n o 27} Lower CCT values correspond to warmer light, with more red content in the spectrum, and higher CCTs correspond to cooler light, with more blue content. As the spectral emission from the lamp is modified to change the CCT, the light emitted often contains more red or blue light. Given the shift in the wavelengths of light emitted from lamps with different CCTs, and the fact that lumens account for the amount of light emitted at particular wavelengths, the efficacy of lamps with different CCTs can vary.

3.4.2.4 Glass Coatings

To increase the UV absorption by the phosphors, the bulb glass can be covered with an antireflective coating. This coating, also referred to as the undercoat or base coat layer, is a refractory oxide, such as aluminum oxide (Al_2O_3), silicon oxide (SiO_2), and titanium oxide (TiO_2). This layer is used to reflect any UV radiation that passes through the phosphor back onto the phosphor, allowing a greater portion of UV to be absorbed. As the phosphors absorb more UV radiation, they will emit more visible light, thereby increasing the overall efficacy of the lamp. When these coatings are used with rare earth phosphors, a good CRI can be achieved while minimizing the phosphor thickness necessary to absorb maximum UV radiation. A recent patent²⁸ by Philips was issued in 2005 for an improved undercoat that reduces the amount of lamp contaminant resulting from the manufacture process. The improved coating covered under the patent contains an aluminum oxide material and a getter material which reacts with

¹ According to the IESNA Lighting Handbook, the CRI of a light source is “a measure of the degree of color shift objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source of comparable color temperature.”

^m DiLaura, D. L., K. W. Houser, R. G. Mistrick, and G. R. Steffy. *Lighting Handbook: Reference and Application, 10th Edition*. New York: Illuminating Engineering Society of North America. IESNA (2011).

ⁿ The 2009 Lamps Rule TSD is available at <http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0131-0147>.

^o According to the IESNA Lighting Handbook, the CCT of a light source is “the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source.”

^o While CCT is a single value, light with the same CCT value may have slightly different properties. Therefore, the lighting industry has defined elliptical regions in chromaticity space (called 4 MacAdam color steps) for specific CCT values (e.g., 2,700 K, 3,000 K, 3,500 K, 4,000 K/4,100 K, 5,000 K, and 6,500 K) in ANSI C78.376-2001. These regions act as a tolerance for the color properties of the lamp.

contaminants. This reduction or elimination of contaminants results in improved lamp arc stability.

3.4.2.5 Higher Efficiency Lamp Diameter

Similar to lamp length, lamp diameter is another design parameter of a fluorescent lamp that can affect efficacy. As Figure 3.4.7 shows, there exists an optimum design diameter for a specific fluorescent lamp type resulting from two opposing effects. First, in small diameter lamps, an increase in diameter decreases the number of electrons and mercury ions that recombine at the bulb wall and produce no light. This lessening of non-radiative recombination results in an increase of optical power output and subsequently a rise in lamp efficacy. However, when the lamp diameter is sufficiently large as to result in minimal non-radiative recombination, a second opposing effect begins to influence the efficacy-diameter relation. With these larger diameter lamps, a further enlargement in diameter causes a greater imprisonment of radiation within the lamp. As the total light output is reduced, the lamp efficacy declines as well. In addition to affecting lamp efficacy, changing the lamp diameter alters the inner surface area of the fluorescent tube. With a larger diameter and therefore surface area, more phosphor is needed to coat the glass, subsequently increasing the cost of the lamp.

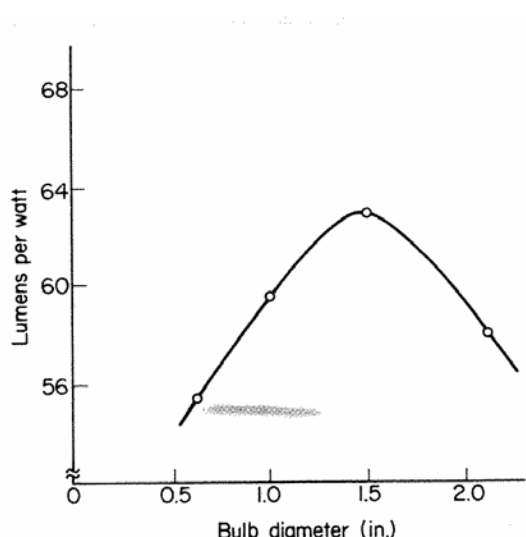


Figure 3.4.7 Bulb Diameter versus Efficacy

Source: IESNA Lighting Handbook: Reference & Application²⁹

DOE only considered lamp diameter as a design option in relation to the migration from T12 to T8 lamps. DOE's research indicated T8 lamps are common replacements for T12 lamps, and though the lumen packages for T8 lamps are often less than that of T12 lamps, in this situation, it does not seem to be significant enough to affect consumer utility. Conversely, DOE's research indicated that T5 lamps have more limited utility as replacements for T8 or T12 lamps due to the fewer available lumen packages for T5 lamp-and-ballast systems. As such, T5 lamps are not proposed as a design option to improving the efficacy of T8 and T12 lamps. See section 3.5.1.3 for more information.

3.4.2.6 Multi-Photon Phosphors

The use of multi-photon phosphors, or quantum-splitting phosphors, can significantly improve lamp efficacy. Because these phosphors emit more than one visible photon for each incident UV photon, a lamp would be able to emit more light in the visible spectrum for the same amount of power. However, there are technical drawbacks with the technology such as light color output, color stability, and phosphor lifetime.³⁰

3.4.3 Basic Structure and Operation of Incandescent Reflector Lamps

An incandescent lamp is a light source in which an electrical current passes through a filament, thermally exciting electrons, which then radiate energy in the form of light and heat. Incandescent lamps consist of a bulb, generally composed of glass such as regular lead, soda lime, or borosilicate heat-resisting glass. Within the bulb, an incandescent lamp contains a filament, filament supports, and sometimes a lamp fill gas. Though early incandescent lamps often used carbon, osmium, and tantalum filaments, current lamps generally use tungsten filaments. Tungsten's low vapor pressure and high melting point allows for high operating temperatures, and consequently high lamp efficacies. The lamp fill gas, though not included in all incandescent lamps, is used to extend the lifetime of the lamp.

IRLs are incandescent lamps with a reflective coating, most commonly composed of aluminum or silver applied directly to the reflector surface. Sealed to the bulb of the IRLs covered in this rulemaking is an E26 medium screw base. By improving directional lighting, reflector lamps place the same illuminance on a specific area with reduced watts. The most common bulb shapes of reflector lamps are R, PAR, BR, and ER. R-, ER- and BR-shaped lamps are primarily for indoor applications, while PAR lamps are usually used outdoors or for spotlighting in retail applications. IRLs can have spot or flood beams. Flood IRLs, which provide a greater distribution of light, typically have a beam spread of 16 to 40 degrees. Spot IRLs usually have a beam spread from 9 to 16 degrees. The ranges change with lamp type, with PAR lamps typically having smaller beam spreads than other IRLs.

Most IRLs on the market today are tungsten-halogen lamps. Tungsten-halogen lamps use a halogen element such as bromine, chlorine, fluorine, or iodine to help increase lifetime of the lamp. In a tungsten-halogen lamp, a small diameter fused quartz envelope, commonly known as a capsule or burner, filled with a halogen molecule surrounds the filament. Above 500 degrees Fahrenheit (F), when tungsten evaporates from the filament, the tungsten molecules combine with the halogen into a gaseous compound. This compound circulates within the envelope until it contacts the filament again. The heat of the filament breaks the compound, freeing the halogen and redepositing the tungsten on the filament. This regenerative process greatly extends the life of incandescent lamps by reducing the loss of tungsten material. Further, because tungsten is not being deposited on the surface, lamp blackening is greatly reduced. However, there is a minimum temperature threshold for the halogen cycle to continue, so if dimmed tungsten-halogen lamps, which employ low voltage operation, become blackened, they should periodically be operated at full power in order to induce the halogen cycle that will remove the tungsten off the capsule wall. One drawback to using halogen is that the halogen capsule is often under high pressure and therefore susceptible to non-passive failure. For this reason, halogen IRLs often employ a thicker protective glass.

3.4.4 IRL Technology Options

The following assessment is a discussion of technology options that improve the efficacy of IRLs. In discussing methods to affect the efficacy of an incandescent lamp, it is important to recognize the interrelation of a lamp's wattage, luminous output, and lifetime. Often the most efficacious incandescent lamps have very low lifetimes and therefore become useless to the consumer. However, it is possible to optimize both efficacy and lifetime so that the lamp still provides utility to the consumer.

3.4.4.1 Higher Temperature Operation

In the operation of an incandescent lamp, a current is passed through a tungsten filament, which when heated, emits light. However, an incandescent light source's spectrum does not fall exclusively in the visible region of the electromagnetic spectrum. This overlap is shown by Curve B, representing the radiant flux from one square centimeter of tungsten at 3,000 K, in Figure 3.4.8.^p By operating the filament at higher temperatures, the spectral output shifts to shorter wavelengths, increasing its overlap with the photopic spectral eye sensitivity. This, in effect, increases the luminous output for a given power input and consequently increases the lamp efficacy. One way to increase the filament temperature is by increasing the wattage of the lamp. As a higher current passes through and a high voltage drop occurs over the filament, the amount of energy released in the form of heat increases, thereby raising the temperature. However, this significantly changes the luminous output of the lamp and may not meet the consumer's needs. Other technologies that address a lamp's ability to operate at high temperatures are filament thickness, inclusion of inert gas fills, and the use of halogen fills, all discussed below. In addition to efficacy, the change in operating temperature also affects color appearance and lifetime of the lamp. As Figure 3.4.9 shows, increasing color temperature is a direct effect of, but not equivalent to, raising operating temperature and also causes an increase in luminous efficacy.

^p In this graph, Curve A and Curve B' are not strictly relevant to this point, and represent the radiant flux from one square centimeter of a blackbody at 3,000 K and the radiant flux from 2.27 square centimeters of tungsten at 3,000 K, respectively.

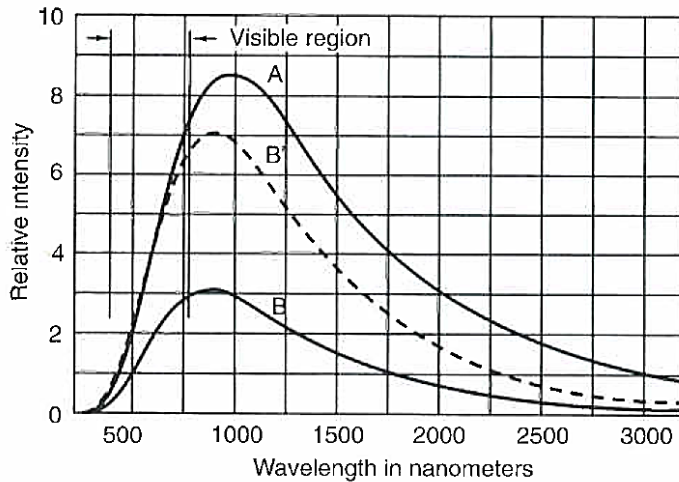


Figure 3.4.8 Radiating Characteristics of Tungsten

Source: IESNA Lighting Handbook: Reference & Application ³¹

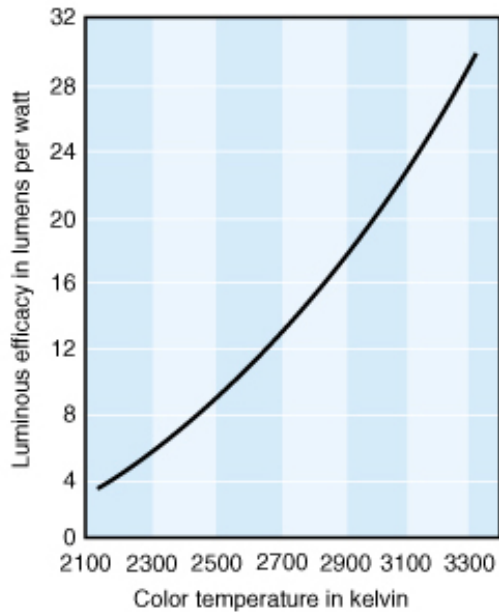


Figure 3.4.9 Luminous Efficacy versus Color Temperature

Source: IESNA Lighting Handbook: Reference & Application ³²

At the melting temperature of tungsten, 6,120 °F, the maximum efficacy of an incandescent lamp with an uncoiled tungsten filament is 53 lm/W. However, to obtain long life in an incandescent lamp, the filament temperature should be significantly below its melting point. As the filament burns hotter, more tungsten evaporates from the filament. When the filament eventually breaks, the lamp fails. This is an example of the clear tradeoff between lamp efficacy and lamp lifetime. Also, to maintain the cool bulb surface, high temperature incandescent lamps often require larger bulbs. This affects the fixtures in which they fit.

3.4.4.2 Novel Filament Materials

Tungsten is a commonly used filament material. However, other filament materials can be considered. In choosing a filament, some advantageous properties are high melting point, low vapor pressure, high strength, high ductility, and good radiating characteristics. While tungsten is primarily used for incandescent lamps, manufacturers also incorporate other metals such as rhenium to improve ductility. However, these lamps are most commonly used for applications requiring vibration-resistant lamps. Novel filament materials, such as nitrides and carbides, have the potential to improve lamp efficacy by emitting more light in the visible spectrum at a given temperature than traditional tungsten filaments. However, these novel filaments can also be brittle, an attribute that can shorten the lamp lifetime.

3.4.4.3 Thinner Filaments

A thinner filament has an increased resistance and therefore an increased operating temperature. As previously discussed, a higher operating temperature results in a higher lamp efficacy. However, as an adverse effect, an incandescent lamp with a thinner filament cannot withstand as much tungsten evaporation as a thicker filament before failing, resulting in a shorter lifetime.

3.4.4.4 Efficient Filament Orientation

Tungsten filament in incandescent lamps can be positioned horizontally or vertically with respect to the base of the bulb. Because the light emitted from the filament is distributed in all directions, one way to improve efficacy is by designing the lamp in a way such that the most amount of light is able to escape the bulb. By positioning the filament in a horizontal orientation, the base of the lamp absorbs much of the emitted light along the length of the coil. However, by positioning the filament in vertical alignment, only a small portion of the light is emitted towards the base. Consequently, more light escapes the bulb and is used for illumination. This can increase the efficacy of an incandescent lamp by approximately eight percent. In most IRLs on the market, the filament is vertically positioned.

3.4.4.5 Efficient Filament Coiling

Coiling of the incandescent lamp filament can increase luminous efficacy. The light output of an incandescent lamp is directly proportional to the light-emitting surface area of the light source. By coiling the filament, a longer filament can be used, increasing luminous output and therefore lamp efficacy. Coiling of the tungsten also affects the heat loss from the filament. The more the filament is coiled, the less the effective area for convective cooling, thereby increasing filament temperature and lamp efficacy. IRLs covered in this rulemaking generally contain filaments of the type C (coiled) or CC (coiled coil). The highly efficacious CC type filament, which is more commonly used, consists of the coil wound into another helical coil.

3.4.4.6 Microcavity Filaments

Texturing of the filament surface can increase surface area and therefore emissivity. Filament surface perforations also can act as waveguides for visible light. One technology includes the creation of microcavity holes in the filament surface. The cavities may then be filled with materials such as tantalum, rhenium, molybdenum, tungsten, SiC, rare earth elements, glass beads, or any combination thereof. Depending on their fabrication, this technology can result in a

variety of effects such as greater control of emissive direction, reduction of infrared radiation, and increased emission efficiency over a certain bandwidth of wavelengths. Ultimately, these effects produce a higher overall efficacy. Research indicates that materials patterned at the submicron level may experience problems with stability.³³

3.4.4.7 Crystallite Filament Coatings

A variety of filament coatings may be used to increase the efficacy of incandescent lamps. Layers of micron or submicron crystallites, comprised of thorium, tantalum, and/or niobium, are deposited on the filament surface. The crystallites are coated with a protective layer of at least one oxide of thorium, hafnium, scandium, yttrium, cerium, or zirconium. This coating increases the emissivity of the filament in the visible part of the spectrum without increasing the infrared radiation. However, as the operating temperature of the filament increases, the emissivity improvement due to the crystallites decreases. Iridium may also be used as a coating to recycle wasted heat.

3.4.4.8 High Reflectance Filament Supports

In a tungsten-halogen capsule, tungsten filament supports can include a reflective face that reflects light to another filament, the reflective face of another filament support, or radially outward, thereby increasing light output/emissivity, and thus efficacy, by providing light that otherwise would have been wasted. The filament supports could also include grooves or an emissive coating with a high emissivity to increase heat dissipation or be formed of a porous ceramic material to increase efficiency.

3.4.4.9 Higher Efficiency Inert Fill Gas

IRLs covered in this rulemaking typically are filled with an inert fill gas whose primary purpose is to reduce the evaporation of tungsten, preventing bulb blackening and increasing lifetime. In addition, this fill gas increases the pressure inside the bulb or halogen capsule. The fill gas also provides a means of convective heat transfer between the heated filament and cool bulb surface. This cooling of the filament represents a power loss and an efficacy reduction due to low temperature operation. Krypton's low thermal conductivity decreases the convective cooling of the filament, allowing for higher temperature operation and therefore higher efficacy. In addition, because the krypton molecule is larger than other elements, such as argon, krypton more effectively slows the evaporation of tungsten and therefore extends the life of the lamp. Xenon, having even lower heat conductivity and larger mass than krypton, can more drastically change efficacy and life but also at a greater cost. Most lamps compliant with the July 2012 standards use xenon as a fill gas. See appendix 7C for a market and life-cycle cost assessment of Xenon.

3.4.4.10 Higher Pressure Tungsten-Halogen Lamps

Increasing the pressure of the halogen capsule by increasing the density of halogen elements can indirectly raise the efficacy of the tungsten-halogen lamp. The increased density of halogen elements raises the probability that an evaporated tungsten element combines with a halogen element in a gaseous compound. Adding more of this gaseous compound in the capsule effectively increases the amount of tungsten re-deposited on the tungsten filament. This can be used to lengthen the lifetime of the tungsten-halogen lamp by decreasing the evaporation rate of

tungsten if the filament temperature is unchanged, or raise its efficacy by increasing the filament temperature while maintaining the evaporation rate of tungsten. A combination of increased lifetime and efficacy may be achieved if the temperature is partially increased and the tungsten evaporation rate is partially decreased.

3.4.4.11 Non-Tungsten-Halogen Regenerative Cycles

The regenerative cycle of filament evaporation and redeposition (where the filament material evaporates and combines with halogen into a gaseous compound and then redeposits on the filament when it contacts it again because the heat of the filament breaks the compound) can be used to greatly increase the life of an incandescent lamp. The filament can burn at a higher temperature than conventional incandescent lamps while maintaining a useful service life. Implementation of a non-tungsten-halogen regenerative cycle depends on incorporating a non-tungsten filament.

3.4.4.12 Infrared Glass Coatings

Infrared coatings on incandescent lamps are used to reflect some of the radiant energy emitted back onto the filament. This infrared radiation then supplies heat to the filament and the operating temperature increases. As discussed earlier, an increase in operating temperature results in a higher light output and therefore an increase in efficacy. In addition, the spectrum of the incandescent lamp shifts toward shorter wavelengths, increasing its overlap with the photopic spectral eye sensitivity and subsequently increasing efficacy for a given power input. These infrared coatings can be in many forms, with new coating types continuing to be developed. Examples include multilayer dichroic filters and crystal lattice structures whose spacing defines a photonic bandgap. They can be applied directly to the glass halogen capsule for tungsten-halogen lamps. However, they are most commonly used in the coating of the halogen capsule, which achieves the greatest directed reflection back onto the filament for the lowest infrared coating usage. Because the halogen capsule is most traditionally in the shape of a cylinder, when infrared coatings are applied to a halogen lamp, the cylindrical shape helps direct the light reflected from the coatings.

3.4.4.13 Higher Efficiency Reflector Coatings

As mentioned previously, IRLs are incandescent lamps with a reflective coating, most commonly composed of aluminum or silver applied directly to the reflector surface. The reflector coating allows these lamps to place the same illuminance on a specific area with reduced watts, thereby increasing efficacy. Though aluminum is most prevalent as a reflector coating in IRLs, silver coatings can also be applied. While aluminum coatings are applied internally by condensation of vaporized aluminum on the inner surface of the bulb, silver can be applied both on the interior and exterior surfaces of the bulb. When applied externally, the silver coating is protected by a copper coating and aluminum finish. Silver coatings are generally preferred over aluminum due to their lower light loss. Gold is also extremely reflective and can be used to increase the amount of directed light and therefore efficacy of the lamp. Mentioned previously as a technology option, an infrared glass coating that reflects the infrared radiation back toward the lamp's filament is also a type of higher efficiency reflector coating. This infrared reflector coating, in the form of multilayer dichroic filters or crystal lattice structures, ultimately increases lamp efficacy by limiting the amount of energy lost through infrared radiation and by increasing lamp operating temperature.

3.4.4.14 Permanent Infrared Reflector Coating Shroud

Infrared glass coatings on capsules can represent a significant portion of manufacturing costs and are usually disposed of when the lamp dies. However, use of a permanent shroud with an infrared reflector coating and a removable and replaceable lamp can increase efficiency while reducing manufacturing costs. The shroud contains a substrate and infrared reflector coating to reflect light back to the filament, thereby increasing efficacy by increasing the operating temperature and shifting the spectrum toward shorter wavelengths, as discussed previously. The shroud and lamp can be configured to be optimally aligned with the lamp reflector.

3.4.4.15 Infrared Phosphor Glass Coating

Salts of the rare earths and other transition group elements contain ions at energy levels that are particularly suited to emit visible light when in transition.³⁴ In the presence of infrared light, these ions will jump to higher energy levels. In some cases, when the ions fall to lower energy levels, light in the visible spectrum is emitted. When used as a coating on a bulb surface, infrared phosphors are able to harvest the emitted infrared energy and convert it to visible light, potentially increasing lamp efficacy.

3.4.4.16 Ultraviolet Phosphor Glass Coating

Similar to infrared phosphor glass coatings, phosphor materials exist that are capable of absorbing high energy radiation and reemitting it at a lower energy level. Specifically, these phosphors convert radiation in shorter wavelengths (UV, violet, and blue spectrums) into longer wavelengths (green and yellow spectrums) of light. The human eye is most responsive to green and yellow visible light, so lumen output is increased by approximately three percent since lumens are weighted by the photopic spectral eye sensitivity.^{35 36}

3.4.4.17 Corner Reflectors

Due to the shape of many reflector lamps, infrared lens technologies can be incorporated in the cover glass to direct infrared radiation back onto the filament. Conventional infrared coatings on reflector lamps direct the infrared light back into the bulb, but not directly onto the filament. Other parts of the lamp absorb some of this heat, which is therefore a source of energy loss. A corner reflector is a technology that incorporates individual corner reflectors into the cover glass. These reflectors' shapes provide the unique ability to reflect light directly back in the direction it came. Therefore any light coming from the filament and impinging on the cover glass will be directed straight back to the filament. These reflectors are covered with a dichroic coating, allowing visible light to pass through and escape while causing infrared radiation to reflect back on the filament. As this radiation heats the filament, the lamp requires less input power to operate at a higher operating temperature, and therefore operates more efficaciously.

3.4.4.18 Electron Stimulated Luminescence

In a process known as cathodoluminescence, visible light can be generated when accelerated electrons strike a phosphor surface. Incandescent filaments produce electrons by thermionic emission. A low voltage cathodoluminescent phosphor that emits green light upon impingement by these thermally ejected electrons may be applied to the lamp. The technology increases light output by utilizing electrons to emit visible light, which otherwise would not have

been produced. This phenomenon can be enhanced by the presence of a lamp fill gas, which may increase the available current for cathode-ray excitation of the phosphor.

3.4.4.19 Higher Efficiency Burners

Halogen burners with halogen infrared reflector (HIR) coatings can be single-ended or double-ended. Single-ended burners feature a lead wire inside of the burner that carries current between the filament and the electrical connection in the IRL's base. The presence of this wire inside of the burner prevents a certain amount of energy from reaching the capsule wall and being reflected (recycled) back to the burner filament. A double-ended burner, on the other hand, features a lead wire outside of the burner, where it does not interfere with the reflectance of energy from the burner wall back to the burner filament. Therefore, a lamp with a double-ended burner is able to reflect more energy back to the filament and thereby, increase lamp efficacy.

3.5 PRODUCT CLASSES

When evaluating and establishing energy conservation standards, DOE divides covered products into classes by (a) the type of energy used; (b) the capacity of the product; or (c) other performance-related features that justify different standard levels, such as features affecting consumer utility. (See 42 U.S.C. 6295(q)) DOE then conducts its analysis and proposes separate standard levels for each product class. DOE applied the criteria of 42 U.S.C. 6295(q) to GSFLs and IRLs to develop product classes in this NOPR analysis. This section of the NOPR TSD describes the factors DOE examined in proposing product classes for GSFLs and IRLs.

3.5.1 General Service Fluorescent Lamps

In setting energy conservation standards for fluorescent lamps, EAct 1992 established product classes based on its definition for fluorescent lamps and on nominal lamp wattages. EAct 1992 set two classes for each lamp type, making a total of eight product classes, as shown in Table 3.5.1. (42 U.S.C. 6295(i)(1)(B))

Table 3.5.1 EAct 1992 Product Classes for General Service Fluorescent Lamps

Lamp Type	Nominal Lamp Wattage
4-foot medium bipin	> 35 W
4-foot medium bipin	≤ 35 W
2-foot U-shaped	> 35 W
2-foot U-shaped	≤ 35 W
8-foot single pin slimline	> 65 W
8-foot single pin slimline	≤ 65 W
8-foot recessed double contact high output	> 100 W
8-foot recessed double contact high output	≤ 100 W

The 2009 Lamps Rule redefined these product classes, establishing divisions based on physical constraints of lamps (*i.e.*, lamp shape and lamp length), lumen package (*i.e.*, SO versus HO), and CCT, as shown in Table 3.5.2.

Table 3.5.2 GSFL Product Classes from the 2009 Lamps Rule

Lamp Type	CCT
4-foot medium bipin	≤ 4,500 K
	> 4,500 K
2-foot U-shaped	≤ 4,500 K
	> 4,500 K
8-foot single pin slimline	≤ 4,500 K
	> 4,500 K
8-foot recessed double contact high output	≤ 4,500 K
	> 4,500 K
4-foot T5, miniature bipin standard output	≤ 4,500 K
	> 4,500 K
4-foot T5, miniature bipin high output	≤ 4,500 K
	> 4,500 K

For this NOPR analysis DOE examined several possible characteristics or features of GSFLs that could warrant separation of covered products into different product classes, including:

- physical constraints of lamps (*i.e.*, lamp shape and lamp length),
- lumen package (*i.e.*, regular versus HO),
- diameter,
- CCT,
- interoperability of lamps on the same ballast system,
- wattage, and
- CRI.

The following subsections discuss these lamp attributes and how they pertain to product class divisions.

3.5.1.1 Physical Constraints of Fluorescent Lamps

The physical constraints of the lamp relate to its shape and length. Because consumers must change a lamp fixture to substitute lamps of different geometries for one another, lamp shape affects utility. DOE research and interviews with manufacturers found that these physical differences prohibit direct replacement. For example, a U-shaped lamp cannot substitute for a linear-shaped lamp in the same fixture. Similarly, given their metric lengths, T5 lamps cannot be used as direct replacements for T8 lamps in some applications. These lamps require different lamp holders (due to differences in length and base type). Further, a 4-foot lamp may have a different utility than an 8-foot lamp, as these lamps generally require different fixtures.

In addition, a lamp's geometry also affects its efficacy. For example, efficacy tends to increase with length. All else being equal, 8-foot lamps generally have higher efficacy values than 4-foot lamps. Also, a 2-foot U-shaped lamp, while having the same overall tube length, is less efficacious than a 4-foot linear lamp, partly because the electrical arc within the tube has to bend to conform to the lamp shape. Given the impact that geometry has on both utility and efficacy, DOE is proposing to establish separate product classes based on lamp geometry.

DOE also conducted an analysis to determine if different lamp base types affect efficacy. DOE found that it was unable to isolate base type alone while holding all other characteristics equal. This is because base type is dependent on a combination of lamp characteristics, specifically length, diameter, and lumen package. Therefore, DOE was unable to determine if base type alone impacted efficacy. However, because base type is already accounted for when considering the product class divisions of length and lumen package, DOE determined no further division is needed.

3.5.1.2 Lumen Package

Lumen package refers to the quantity of light that a lamp-and-ballast system provides to a consumer. DOE observed that consumers tend to use systems with different lumen packages for different applications. For example, high-lumen-output systems may be installed in certain high-ceiling or outdoor applications, where large quantities of light are needed. Alternatively, standard-lumen-output systems might be installed in lower-ceiling applications such as offices or hospitals, where, for example, distance between the light source and the illuminated surfaces is not as large. These notable differences in the application of SO versus HO lamps indicate a difference in utility.

To obtain a high lumen package, certain lamps are designed to operate with ballasts that run the lamps at high currents. For example, 8-foot RDC HO lamps and 4-foot MiniBP HO lamps tend to operate at higher currents than 8-foot SP slimline lamps and 4-foot MiniBP SO lamps, respectively. This difference in operating design increases the quantity of light per unit lamp length for the 8-foot RDC HO and 4-foot MiniBP HO lamps. Operating lamps at a higher current also decreases efficacy. For example, the efficacy of an 8-foot RDC HO lamp is as much as 10 percent lower than that of a comparable 8-foot SP slimline lamp. Given the observed utility distinctions and notable efficacy differences between SO and HO lamps, DOE is proposing to establish separate product classes based on lumen package.

3.5.1.3 Diameter

As discussed in section 3.4.2.5, lamp diameter is a feature of a lamp which impacts efficacy. In general, DOE considers lamp diameter as a design option, and did not consider using it as a basis for developing product classes. Manufacturer marketing literature and general guidance on lighting design and installation often promote T8 lamp-and-ballast systems as higher efficacy, energy-saving substitutes for T12 lamp-and-ballast systems. Such substitute systems have the same lengths and bases, offer comparable lumen output, and can fit within the same fixtures. Therefore, DOE recognizes that although the diameter of the lamp will affect the efficacy, the utility provided to the end-user is comparable and/or equivalent.

As stated earlier, DOE generally considers lamp diameter a design option when there is no associated decrease in utility. However, DOE will consider separate product classes for different diameter lamps when there is a decrease in utility, such as with the T5 MiniBP lamps. DOE's test procedure for GSFLs requires lamps to be tested using low frequency reference ballast settings unless only high frequency settings are available. Because only high frequency settings are available for T5 lamps, these lamps are tested under different conditions than T8 lamps. High frequency operation increases lamp lumen output; thus, T5 lamps appear to be more efficacious than similar T8 lamps. If T5 and T8 lamps were included in the same product class,

T8 lamps could be eliminated due to this difference in efficacy. T8 lamps, however, provide consumer utility because more lumen packages are available for T8 than for T5 lamp-and-ballast systems. Consumers tend to use systems with different lumen packages for different applications. Most of the commercially available 4-foot T5 MiniBP SO lamps offer the same initial lumen output. Specifically, 80 percent of standards-compliant 4-foot T5 MiniBP SO lamps have an initial lumen output of 2900 lumens.⁹ On the other hand, 4-foot MBP T8 lamps offer a much wider range of initial lumen outputs. Additionally, fluorescent lamps are a component of a system and their performance characteristics are related to the ballast on which they operate. Each fluorescent lamp ballast has a specified BF, which is typically used to adjust the lumen package of a lamp-and-ballast system. The vast majority of ballasts designed to operate 4-foot T5 MiniBP SO lamps have normal BFs, which further limits lumen package options for these systems. Ballasts that operate 4-foot MBP T8 lamps, however, are available with a larger range of BF options (*i.e.*, low, normal, and high). Thus, a standard that eliminates 4-foot MBP T8 lamps would result in a substantial decrease in available lumen package options and negatively impact consumer utility.

Further, a standard which eliminates 4-foot T8 MBP lamps could result in increased system energy consumption. As mentioned above, the vast majority of commercially available ballasts designed to operate 4-foot T5 MiniBP SO lamps are normal BF PS ballasts with a typical BF of 1.0. The most common BF for ballasts of the same starting method (PS) designed to operate 4-foot T8 MBP lamps is 0.88. Although the high frequency reference arc power of full wattage 4-foot T5 MiniBP SO lamps is lower than the high frequency reference arc power of full wattage 4-foot T8 MBP lamps (27.8 W and 29.0 W, respectively), the higher BF of T5 SO ballasts results in higher overall system energy consumption compared to the typical T8 MBP system.

Therefore, due to the effect of diameter on both efficacy and utility, and the potential for increased energy consumption, DOE is proposing to establish separate product classes for 4-foot T5 MiniBP lamps.

3.5.1.4 Correlated Color Temperature

As discussed in section 3.3.1.3, in general terms, the CCT is a measure of the perceived color of the white light emitted from the lamp. The perception of light affords consumers a different utility for lamps with different CCT values. Additionally, as the SPD of the lamp is modified to change the CCT, the lamp efficacy can vary. Due to their greater blue light content, higher CCT fluorescent lamps tend to have lower efficacies.

For covered fluorescent lamps, CCT ranges span between 2,500 K and 7,000 K. Feedback from manufacturer interviews indicates that lamps with CCTs greater than 4,500 K begin to show a considerable decline in efficacy. Given the impact on efficacy and utility, DOE is proposing to establish separate product classes for lamps with CCT less than or equal to 4,500 K and greater than 4,500 K.

⁹ Data in catalogs is often reported at 35 °C.

3.5.1.5 Ballast Interoperability

Not all lamps operate on the same ballast. Even if lamps have similar geometries, different ballasts may be required for their operation. However, DOE treats ballast interoperability as an economic issue (in the life-cycle cost and national impact analyses) rather than a product class issue. In other words, if a consumer needs to change the ballast to replace a lamp, then the installed cost of both the lamp and ballast are factored into the net present value equation. Therefore, DOE is not proposing to establish a product class division based on ballast interoperability.

3.5.1.6 Wattage

The main function of a lamp is to provide lumen output, while other attributes such as CCT, for example, contribute to utility. Wattage measures the power consumed by a lamp in providing its service. Therefore, DOE does not construe wattage as a direct measurement of utility.

Furthermore, dividing product classes by wattage locks the standards for GSFLs to a static wattage structure. While this structure may reflect current product availability, the market may evolve over time, shifting to different wattages. Therefore, DOE is not proposing to establish product classes based on wattage.

3.5.1.7 Color Rendering Index

DOE also considered setting product classes for GSFLs based on CRI. DOE analyzed the impact of CRI on efficacy when keeping all other lamp characteristics constant. DOE found no correlation between CRI and efficacy and therefore concluded that CRI did not have a direct impact on efficacy. DOE did confirm, however, that the majority of lamps with higher efficiency phosphors also offered higher CRIs as discussed in section 3.4.2.3. For example, lamps with 800-series rare earth phosphors, considered the most efficient combination of phosphors, had the highest CRI values typically ranging from 80 to 86. However, there was no indication of consistently increasing efficacy with increasing CRI values for the lamps within each specific phosphor series.

DOE recognizes that CRI provides utility because a high CRI light source renders colors well and can be required for color sensitive applications. Although CRI is associated with a change in utility, because DOE found no direct impact on efficacy associated with CRI, DOE is not proposing to establish separate product classes based on CRI.

3.5.1.8 Product Class Summary

The GSFL product classes being proposed in this NOPR analysis are summarized in Table 3.5.3.

Table 3.5.3 GSFL NOPR Analysis Product Classes

Lamp Type	CCT
4-foot medium bipin	≤ 4,500 K
	> 4,500 K
2-foot U-shaped	≤ 4,500 K
	> 4,500 K
8-foot single pin slimline	≤ 4,500 K
	> 4,500 K
8-foot recessed double contact high output	≤ 4,500 K
	> 4,500 K
4-foot T5, miniature bipin standard output	≤ 4,500 K
	> 4,500 K
4-foot T5, miniature bipin high output	≤ 4,500 K
	> 4,500 K

3.5.2 Incandescent Reflector Lamps

In setting energy conservation standards for IRLs, EPC Act 1992 differentiated IRLs by wattage and established six nominal wattage ranges or “bins,” shown in Table 3.5.4. (42 U.S.C. 6295(i)(1)(B))

Table 3.5.4 EPC Act 1992 Product Classes for Incandescent Reflector Lamps

Nominal Lamp Wattage
40-50
51-66
67-85
86-115
116-155
156-205

The 2009 Lamps Rule redefined these product classes, establishing divisions based on lamp diameter, voltage, and spectrum. DOE is proposing to maintain these divisions, as shown in Table 3.5.5.

For this NOPR analysis DOE examined several possible characteristics or features of IRLs that could warrant separation of covered products into different product classes, including:

- wattage,
- spectrum,
- diameter,
- voltage,
- beam spread,
- center beam candle power, and
- length.

The following subsections discuss these lamp attributes and how they pertain to product class divisions.

Table 3.5.5 IRL Product Classes from the 2009 Lamps Rule

Lamp Type	Diameter (in inches)	Voltage
Standard Spectrum	> 2.5	≥ 125 V
		< 125 V
	≤ 2.5	≥ 125 V
		< 125 V
Modified Spectrum	> 2.5	≥ 125 V
		< 125 V
	≤ 2.5	≥ 125 V
		< 125 V

3.5.2.1 Wattage

As wattage increases for incandescent lamps, efficacy also generally increases. Wattage also generally indicates the amount of light produced. Instead of creating product class divisions based on wattage, DOE developed a single standard per product class as an equation that relates lumens to wattage and sets a minimum efficacy requirement that varies by wattage. The equation is able to use a single range of wattages while taking into account variation in efficacy by wattage. Furthermore, an equation relating lumens to wattage allows for a product class structure that encompasses all wattages and can better keep pace with the market should it shift to new wattages over time. Chapter 5 of this NOPR TSD provides more information on the selection of ELs using this equation.

3.5.2.2 Spectrum

Modified spectrum^r IRLs provide unique utility to consumers by providing a different type of light than standard spectrum lamps, much like fluorescent lamps with different CCT values. However, the same technologies that modify the spectral emission of a lamp also decrease lamp efficacy. To modify the spectrum, the coating absorbs a portion of the light emission from the filament. Neodymium coatings or other coatings on modified spectrum lamps absorb some of the visible emission from the incandescent filament (usually red), creating a modified, reduced spectral emission. Since the neodymium or other coatings absorb some of the lumen output from the filament, these coatings decrease the efficacy of the lamp.

^r As found in 10 CFR 430.2:

Modified spectrum means, with respect to an incandescent lamp, an incandescent lamp that—

- (1) Is not a colored incandescent lamp; and
- (2) When operated at the rated voltage and wattage of the incandescent lamp—
 - (A) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies below the black-body locus; and
 - (B) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies at least 4 MacAdam steps, as referenced in IESNA LM-16, distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.

Because of the impact on both efficacy and utility, DOE is proposing to establish separate product classes based on spectrum. DOE is planning to establish separate product classes for standard spectrum IRLs (those without modification to the spectral emission) and modified spectrum IRLs (some portion of the spectral emission is absorbed).

3.5.2.3 Diameter

IRL diameter provides a distinct utility to the consumer, such as the ability to be installed in smaller fixtures. The diameter of an IRL also has an impact on its efficacy. Smaller diameter lamps have an inherently lower optical efficiency than larger diameter lamps with similar filaments. Additionally, technology options that improve efficacy that are available to larger lamps are not necessarily available to small diameter lamps given the spatial constraints. Therefore, because of the impact on both efficacy and consumer utility, DOE is proposing to establish separate product classes for small diameter lamps, with a diameter of 2.5 inches or less, and large diameter lamps, with a diameter greater than 2.5 inches.

3.5.2.4 Rated Voltage

Existing DOE test procedures provide for lamps rated at 130 V to be tested at 130 V and for lamps rated at 120 V to be tested at 120 V. However, DOE is aware that a large number of consumers actually operate 130 V lamps at 120 V, which results in longer lifetime but lower efficacy. With a single efficacy level (EL) for lamps rated at each voltage, this situation would effectively lead to a lower efficacy requirement for these 130 V lamps that are run at 120 V, compared to 120 V lamps run at 120 V. The 130 V lamps would not require the same level of technology as 120 V lamps to meet the same standard, and, thus, they would be cheaper to produce. Therefore, setting higher standards for IRLs without accounting for voltage differences could result in increased migration to 130 V lamps instead of the 120 V lamps, which could increase energy consumption.

For example, if DOE were to adopt a minimum efficacy requirement that would effectively require improved HIR technology for 120 V lamps, due to differences in the test procedures for lamps rated at 130 V, a 130 V lamp may only need to employ an improved halogen technology, which would be less costly. If DOE does not establish a separate standard for lamps rated at 130 V, more consumers may purchase 130 V lamps because they are less expensive. When consumers operate these lamps at 120 V, they may need to purchase more lamps to obtain sufficient light output, thereby increasing energy consumption. Therefore, to preserve the energy savings intended by these standards, DOE is proposing to establish two separate product classes: (1) lamps with a rated voltage less than 125 V, and (2) lamps with a rated voltage greater than or equal to 125 V.

3.5.2.5 Beam Spread

DOE considered setting product classes for IRLs based on beam spread values or beam spread categories (spot, flood, narrow flood, etc.). DOE conducted an analysis to determine if beam spread impacted efficacy by comparing lamps with the same characteristics but different beam spreads. DOE concluded that while there might be different utility for consumers through the light distribution patterns of lamps with different beam spreads, the beam spread does not affect the efficacy of the lamp. Thus, DOE is not proposing to establish separate product classes for beam spread.

3.5.2.6 Center Beam Candle Power

Center beam candle power (CBCP) provides a measure of the light intensity at the center of an angle and is correlated to beam spread. DOE conducted an analysis to determine if CBCP impacted efficacy by comparing lamps with the same characteristics but different CBCP values. DOE concluded that while there might be different utility for consumers through the variation in light intensity between lamps with different CBCP values, the CBCP does not affect the efficacy of the lamp. Thus, DOE does not plan to establish separate product classes for CBCP.

3.5.2.7 Length

DOE considered setting product classes for IRLs based on maximum overall length of the lamp. DOE conducted an analysis to determine if length impacted efficacy by comparing lamps with the same characteristics, but different lengths. DOE was unable to confirm a relationship between length and efficacy. DOE concluded that while there may be a certain consumer utility for lamps with different lengths, the efficacy impact did not justify establishing product classes based on length. Therefore, DOE is not proposing to establish product classes based on lamp length.

3.5.2.8 Product Class Summary

The IRL product classes being proposed in this NOPR are summarized in Table 3.5.6.

Table 3.5.6 IRL NOPR Analysis Product Classes

Lamp Type	Diameter (in inches)	Voltage
Standard Spectrum	> 2.5	≥ 125 V
		< 125 V
	≤ 2.5	≥ 125 V
		< 125 V
Modified Spectrum	> 2.5	≥ 125 V
		< 125 V
	≤ 2.5	≥ 125 V
		< 125 V

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CHAPTER 4. SCREENING ANALYSIS

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CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter discusses the U.S. Department of Energy's (DOE) screening analysis of the technology options identified for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). As discussed in chapter 3 of this technical support document (TSD), DOE consults with industry, technical experts, and other interested parties in developing a list of technology options to propose. The purpose of the screening analysis is to evaluate the list of options and determine which to consider further and which to screen out.

Section 325(o)(2) of the Energy Policy and Conservation Act (EPCA) provides that any new or revised standard must be designed to achieve the maximum improvement in energy efficiency that is determined to be technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)) In view of the EPCA requirements for determining whether a standard is technologically feasible and economically justified, Appendix A to Subpart C of Title 10, Code of Federal Regulations (CFR), Part 430, "Procedures, Interpretations, and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products" (the Process Rule) sets forth procedures to guide DOE in its consideration and promulgation of new or revised efficiency standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular, sections 4(b)(4) and 5(b) of the Process Rule provide guidance to DOE for determining which technology options are unsuitable for further consideration:

1. **Technological feasibility.** DOE will consider technologies incorporated in commercially available products or in working prototypes to be technologically feasible.
2. **Practicability to manufacture, install, and service.** If mass production of a technology and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time the standard requires compliance, then DOE will consider that technology practicable to manufacture, install, and service.
3. **Adverse impacts on product utility or product availability.** If DOE determines a technology would have significant adverse impact on the utility of the product to significant subgroups of consumers, or would result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not further consider this technology.

4. **Adverse impacts on health or safety.** If DOE determines that a technology will have significant adverse impacts on health or safety, it will not further consider this technology.

Section 4.2 of this chapter discusses the technology options DOE screened out from further consideration. Section 4.3 summarizes those options. Section 4.4 lists the remaining technology options not screened out and being proposed as design options in this notice of proposed rulemaking (NOPR). The market and technology assessment (see chapter 3 of this NOPR technical support document [TSD]) discusses in detail all technology options analyzed in this NOPR.

4.2 SCREENED OUT TECHNOLOGIES

This section addresses the technologies that DOE screened out, having considered the following four factors: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) adverse impacts on product utility or product availability; and (4) adverse impacts on health or safety.

4.2.1 General Service Fluorescent Lamps

4.2.1.1 Multi-Photon Phosphors

Theoretically, the use of multi-photon phosphors, or quantum-splitting phosphors, could significantly improve lamp efficacy. By emitting more than one visible photon for each ultraviolet photon, a lamp would be able to emit more light for the same amount of power. Researchers at Georgia Tech were issued a patent for an oxide-based phosphor doped with praseodymium and atoms of at least one activator that produces two visible light photons from a single ultraviolet light photon.¹ However, development of this technology for use in lighting products remains in the research phase and DOE is unaware of any prototypes or commercialized products that incorporate multi-photon phosphors.² Further, researchers have identified technical drawbacks to this technology such as light color output, color stability, and phosphor lifetime.³ Thus, DOE screened out this technology option based on the first criterion, technological feasibility, and is not proposing multi-photon phosphors as a design option for improving the efficacy of GSFLs.

4.2.2 Incandescent Reflector Lamps

4.2.2.1 Novel Filament Materials

Novel filament materials such as nitrides and carbides have the potential to improve lamp efficacy by emitting more light in the visible spectrum at a given temperature than traditional tungsten filaments.^{4 5} However, DOE is unaware of any prototypes or commercialized products that utilize such filaments and therefore, it is unclear that this option is technologically feasible. Furthermore, DOE understands that issues, such as prohibitive brittleness of the filament, limit implementation of this technology and could potentially negatively impact its utility to consumers. Therefore, DOE screened out novel filament materials on the basis of the first criterion,

technological feasibility; the second criterion, practicability to manufacture; and the third criterion, potential impacts on utility to consumers, and is not proposing novel filament materials as a design option for improving the efficacy of IRLs.

4.2.2.2 Microcavity Filaments

By fabricating microcavities on the incandescent lamp filament, it is theoretically possible to increase a lamp's emissivity, and therefore its efficacy. Sandia National Laboratories researchers examined microcavity resonance in a tungsten photonic lattice⁶ and DOE found multiple patents referencing this technology.^{7 8} However, DOE is unaware of any prototypes or commercialized products that utilize microcavity filaments and therefore, it is unclear that this option is technologically feasible. Additionally, research indicates that materials patterned at the submicron level may experience problems with stability.⁹ Therefore, DOE screened out microcavity filaments based on the first criterion, technological feasibility; the second criterion, practicability to manufacture; and third criterion, adverse impacts on consumer utility, and is not proposing filaments with microcavities as a design option for improving the efficacy of IRLs.

4.2.2.3 Crystallite Filament Coatings

DOE screened out crystallite filament coatings, which are oxide-covered micron or submicron crystallites composed of thorium, tantalum, or niobium. These coatings can be used to increase the light emissivity of a lamp's filament.¹⁰ However, DOE is unaware of any prototypes or commercialized products that utilize crystallite filament coatings and therefore, it is unclear that this option is technologically feasible. Further, using crystallite filament coatings may require additional manufacturing techniques, such as chemical vapor deposition. DOE understands that these techniques are not in use in the mass production of IRLs. Therefore, DOE screened out this option based on the first criterion, technological feasibility and the second criterion, practicability to manufacture, and is not proposing crystallite filament coatings as a design option for improving the efficacy of IRLs.

4.2.2.4 High Reflectance Filament Supports

Filament supports can have a reflective face that redirects light to a filament, another reflector, or radially outward.¹¹ The filament supports could also include grooves, a coating with a high emissivity to increase heat dissipation, or be formed of a porous ceramic material to increase efficiency. Halogen capsules have not incorporated these structures due to potential efficacy losses. Because DOE is unaware of any prototypes or commercialized products that utilize high reflectance filament supports, it is unclear that this option is technologically feasible. Therefore, DOE screened out high reflectance filament supports based on the first criterion, technological feasibility; and second criterion, practicability to manufacture, and is not proposing high reflectance filament supports as a design option for improving the efficacy of IRLs.

4.2.2.5 Non-Tungsten-Halogen Regenerative Cycles

The regenerative cycle of filament evaporation and redeposition can be used to greatly increase the life of an incandescent lamp and improve lumen maintenance. The filament can burn at a higher temperature than conventional incandescent lamps while maintaining a useful service life. DOE understands that other regenerative cycles also may be possible for non-tungsten filament materials.¹² However, as noted in section 4.2.2.1, DOE has screened out the use of novel filament materials which include non-tungsten filament materials on the basis of the first, second and third screening criteria. Because use of the non-tungsten-halogen regenerative cycles would depend on incorporating a non-tungsten filament, DOE screened out such cycles from consideration based on the same three criteria, technological feasibility, practicability to manufacture, and potential adverse impacts on utility to consumer. Therefore, DOE is not proposing non-tungsten-halogen regenerative cycles as a design option for improving the efficacy of IRLs.

4.2.2.6 Higher Efficiency Gold Reflector Coatings

Gold is one type of higher efficiency reflector coating that is extremely reflective and has the potential to increase the amount of directed light, and therefore the efficacy, of IRLs.^{13 14} However, DOE found that gold reflectivity diminishes at and below blue-green wavelengths, which may decrease the color quality of light,¹⁵ thereby impacting product utility. Further, gold reflector coatings have thus far been used mainly in lamps that produce infrared and near-infrared light (*e.g.*, heat lamps or lamps intended to change the color of light, such as those used for photography purposes). Therefore, use of these reflector coatings may not be suitable for general lighting applications. Hence, DOE screened out high efficiency gold reflector coatings based on the third criterion, adverse impact on product utility, and is not proposing higher efficiency gold reflector coatings as a design option for improving the efficacy of IRLs. However, DOE did not screen out other higher efficiency reflector coatings, such as aluminum and silver, because they do not have an adverse impact on product utility and meet DOE's screening criteria. Therefore, DOE is proposing higher efficiency reflector coatings, with the exception of gold reflector coatings, as design options for improving the efficacy of IRLs.

4.2.2.7 Permanent Infrared Reflector Coating Shroud

Infrared reflector coatings on halogen capsules allow visible light to pass through the glass envelope, while reflecting the infrared energy back to the filament. As this coating must be replaced whenever the lamp reaches end of life, it represents a significant component of manufacturing costs. A permanent shroud with infrared reflector coating would therefore increase efficiency while also reducing manufacturing costs.¹⁶ However, DOE is unaware of any prototypes or commercialized products that utilize a permanent infrared reflector coating shroud and therefore, it is unclear that this option is technologically feasible. Therefore, DOE screened out permanent infrared reflector coating shroud based on the first criterion, technological feasibility and the second criterion, practicability to manufacture, and is not proposing it as a design option for improving the efficacy of IRLs.

4.2.2.8 Infrared Phosphor Glass Coating

When used as a coating on the bulb surface, infrared phosphors harvest the emitted infrared energy and convert it to visible light, potentially increasing lamp efficacy.¹⁷ However, DOE is unaware of any prototypes or commercialized products that utilize infrared phosphor glass coatings and therefore, it is unclear that this option is technologically feasible. Therefore, DOE screened out this option based on the first criterion, technological feasibility and second criterion, practicability to manufacture, and is not proposing infrared phosphor glass coatings as a design option for improving the efficacy of IRLs.

4.2.2.9 Ultraviolet Phosphor Glass Coating

Similar to infrared phosphor glass coating, when used as a coating on the bulb surface, ultraviolet phosphors absorb ultraviolet radiation and convert it to visible light.^{18, 19} However, DOE is unaware of any prototypes or commercialized products that utilize ultraviolet phosphor glass coatings and therefore, it is unclear that this option is technologically feasible. Therefore, DOE screened out this option based on the first criterion, technological feasibility and second criterion, practicability to manufacture, and is not proposing ultraviolet phosphor glass coatings as a design option for improving the efficacy of IRLs.

4.2.2.10 Corner Reflectors

Corner reflectors incorporated into the cover glass of IRLs have the potential to increase lamp efficacy by redirecting infrared radiation back onto the filament.^{20, 21} However, DOE is unaware of any prototypes or commercialized products that utilize corner reflectors and therefore, it is unclear that this option is technologically feasible. Further, using corner reflectors, which entails an additional disc requiring external fabrication and installation in the lamp, may necessitate manufacturing techniques not currently available for mass production. Therefore, DOE screened out this option based on the first criterion, technological feasibility and the second criterion, practicability to manufacture, and is not proposing corner reflectors as a design option for improving the efficacy of IRLs.

4.2.2.11 Electron Stimulated Luminescence

When struck by the electrons thermally ejected from a lamp's filament, cathodoluminescent phosphors emit visible light.²² However, DOE is unaware of any prototypes or commercialized products that utilize electron stimulated luminescence and therefore, it is unclear that this option is technologically feasible. Therefore, DOE screened out this technology option on the basis of the first criterion, technological feasibility and the second criterion, practicability to manufacture, and is not proposing electron stimulated luminescence as a design option for improving the efficacy of IRLs.

4.2.2.12 Higher Efficiency Burners for Small Diameter IRLs

Double-ended halogen burners with halogen infrared reflector (HIR) coatings feature a lead wire outside of the capsule, where it does not interfere with the reflectance of energy from the capsule wall back to the capsule filament. Therefore, a lamp with a double-ended burner is able to reflect more energy back to the filament than a single-ended burner, which incorporates the lead wire inside the capsule.

However, DOE research and feedback from manufacturers has indicated that the double-ended HIR burner configuration does not generally fit into smaller diameter IRLs (i.e. diameter less than or equal to 2.5 inches) such as the PAR20, without changing the physical shape of the lamp. A change in the lamp's physical shape may impact whether the lamp can fit into standard fixtures, and thereby affect product utility. Thus, DOE believes the higher efficiency burner technology option is not applicable to small diameter lamps.

DOE is proposing to screen out this technology option for small diameter IRLs on the basis of the third criterion, adverse impacts on product utility. However, DOE is not proposing to screen out higher efficiency burner technology for large diameter IRLs (i.e. diameters greater than 2.5 inches), because it does not adversely impact product utility and meets DOE's screening criteria. Therefore, DOE is proposing higher efficiency burners, with the exception of application to small diameter IRLs, as a design option for improving the efficacy of IRLs.

4.3 SUMMARY OF TECHNOLOGY OPTIONS SCREENED OUT

The following tables summarize the technology options DOE is proposing to screen out and the associated screening criteria.

Table 4.3.1 GSFL Technology Options Screened Out of the Analysis

Design Option Excluded	Screening Criteria
Multi-Photon Phosphors	Technological feasibility

Table 4.3.2 IRL Technology Options Screened Out of the Analysis

Design Option Excluded	Screening Criteria
Novel Filament Materials	Technological feasibility, Practicability to manufacture, install, and service Product utility to consumers
Microcavity Filaments	Technological feasibility, Practicability to manufacture, install, and service, Adverse impact on product utility
Crystallite Filament Coatings	Technological feasibility, Practicability to manufacture, install, and service
High Reflectance Filament Supports	Technological feasibility, Practicability to manufacture, install, and service
Non-Tungsten-Halogen Regenerative Cycles	Technological feasibility, Practicability to manufacture, install, and service, Adverse impact on product utility
Higher Efficiency Gold Reflector Coatings	Adverse impact on product utility
Permanent Infrared Reflector Coating Shroud	Technological feasibility, Practicability to manufacture, install, and service

Design Option Excluded	Screening Criteria
Infrared Phosphor Glass Coating	Technological feasibility, Practicability to manufacture, install, and service
Ultraviolet Phosphor Glass Coating	Technological feasibility, Practicability to manufacture, install, and service
Corner Reflectors	Technological feasibility, Practicability to manufacture, install, and service
Electron Stimulated Luminescence	Technological feasibility, Practicability to manufacture, install, and service
Higher Efficiency Burners for Small Diameter IRLs (less than or equal to 2.5 inches)	Adverse impact on product utility

4.4 REMAINING TECHNOLOGIES

After screening out those technologies in accordance with the policies set forth in 10 CFR Part 430, Subpart C, Appendix A, (4)(a)(4) and 5(b), DOE is proposing the design options in the following list as viable means for improving efficacy. These design options are being utilized in commercially available lamps and have demonstrated that they are technologically feasible, practicable to manufacture, install, and service, and do not result in adverse impacts on product utility/availability or health and safety. The market and technology assessment (see chapter 3 of this NOPR TSD) provides a detailed description of these design options.

4.4.1 General Service Fluorescent Lamp Design Options

- Highly Emissive Electrode Coatings
- Higher Efficiency Lamp Fill Gas Composition
- Higher Efficiency Phosphors
- Glass Coatings
- Higher Efficiency Lamp Diameter

4.4.2 Incandescent Reflector Lamp Design Options

- Higher Temperature Operation
- Thinner Filaments
- Efficient Filament Orientation
- Efficient Filament Coiling
- Higher Efficiency Inert Fill Gas
- Higher Pressure Tungsten-Halogen Lamps
- Infrared Glass Coatings
- Higher Efficiency Reflector Coatings (with the exception of gold reflector coatings)
- Higher Efficiency Burners (with the exception of higher efficiency burners in small diameter IRLs, specifically of diameters less than or equal to 2.5 inches)

DOE is proposing these options in the engineering analysis as a viable means for improving lamp efficacy.

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CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The U.S. Department of Energy (DOE) performed engineering analyses for both general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). This chapter of the notice of proposed rulemaking (NOPR) technical support document (TSD) provides the analyses DOE used to study representative lamps, to select efficacy levels (ELs), and to develop power rating estimates for the products analyzed. After selecting representative product classes, DOE then selects lamps that represent the baseline efficacy, as well as more efficacious substitutes for those baseline lamps. DOE uses these more efficacious lamps to develop ELs. While DOE establishes ELs based on lamp designs for the engineering analysis, for GSFLs it also develops lamp-and-ballast systems for use in the life-cycle cost (LCC) analysis and national impact analysis (NIA) because fluorescent lamps and ballasts operate together in practice.

In energy conservation rulemakings for other products, DOE often develops cost-efficiency relationships in the engineering analysis. However, for this rulemaking, DOE derives ELs in the engineering analysis and end-user prices in the product price determination. By combining the results of the engineering analysis and the product price determination, DOE derives typical inputs for use in the LCC and NIA. See chapter 7 of this TSD for discussion of DOE's methodology for determining product prices.

5.2 METHODOLOGY OVERVIEW

To the extent possible, DOE bases the engineering analysis on commercially available lamps that incorporate the design options identified in the technology assessment and screening analysis (chapters 3 and 4 of this TSD). The engineering analysis for each of the two categories of lamps DOE analyzes in this rulemaking (*i.e.*, GSFLs and IRLs) follows a similar approach:

1. *Select representative product classes:* DOE first reviews covered lamps and the associated product classes. When multiple product classes are needed, DOE selects certain classes as “representative” and concentrates its analytical effort on these classes. DOE selects representative product classes primarily because of their high market volumes.
2. *Select Baseline Lamps:* For each representative product class, DOE selects a baseline lamp as a reference point against which to measure changes resulting from energy conservation standards. Typically, a baseline lamp is the most common, least efficacious lamp sold in a given product class. For this NOPR analysis, DOE used performance data presented in manufacturer catalogs to determine lamp efficacy. DOE also considers other lamp characteristics in choosing the most appropriate baseline for each product class such as wattage, lumen output, and lifetime. DOE generally selects commercially available lamps as baselines. For this rulemaking, DOE also considered modeled baseline lamps developed for the 8-foot recessed double contact (RDC) high output (HO), 4-foot T5 miniature bipin (MiniBP) standard output (SO), and 4-foot T5 MiniBP HO product classes (see section 5.3.3 for further detail).
3. *Identify More Efficacious Substitutes:* DOE selects higher efficacy lamps as replacements for each of the baseline lamps. When selecting higher efficacy lamps, DOE considers only

design options that meet the criteria outlined in the screening analysis (chapter 4 of this TSD). For GSFLs, DOE pairs each lamp with an appropriate ballast because fluorescent lamps are a component of a system, and their performance is related to the ballast on which they operate.

4. *Determine Efficacy Levels:* After identifying more efficacious substitutes for each baseline lamp, DOE develops ELs. DOE bases its analysis on three factors: (1) the design options associated with the specific lamps studied; (2) the ability of lamps across wattages to comply with the EL of a given product class;^a and (3) the maximum technologically feasible efficacy level. DOE then scales the ELs of representative product classes to those product classes not directly analyzed.

The sections that follow discuss how DOE applies this methodology to each GSFL and IRL product class to create the engineering analysis.

5.3 GENERAL SERVICE FLUORESCENT LAMPS

5.3.1 Representative Product Classes

As discussed in the market and technology assessment (chapter 3 of this NOPR TSD), DOE considered 12 product classes for GSFLs based on three class-setting factors: correlated color temperature (CCT), physical constraints, and lumen package. Of these product classes, DOE chose the following five classes as representative because of their high shipment volumes: 4-foot medium bipin (MBP), 8-foot single pin (SP) slimline, 8-foot RDC HO, 4-foot T5 MiniBP standard output (SO), and 4-foot T5 MiniBP HO – all with a CCT less than or equal to 4,500 kelvin (K). DOE directly analyzed these representative product classes. As indicated in shipment data, 4-foot MBP lamps constitute the vast majority of GSFL sales. These are followed, in decreasing order, by 4-foot MiniBP SO and HO lamps, 8-foot SP slimline lamps, 8-foot RDC HO lamps, and 2-foot U-shaped lamps. Given the relatively small market share of 2-foot U-shaped lamps, DOE did not directly analyze these products. In addition, as lamps with CCTs greater than 4,500 K represent small market shares of total GSFL sales, DOE only directly analyzed lamps with CCTs less than or equal to 4,500 K. See chapter 3 of this TSD for more information on lamp shipments.

Table 5.3.1 lists the 12 product classes and identifies the representative product classes (indicated by gray shading) that DOE is considering in this NOPR analysis.

^a ELs span multiple lamps of different wattages. In selecting ELs, DOE considered whether these multiple lamps can meet the standard levels.

Table 5.3.1 Representative Product Classes for General Service Fluorescent Lamps

Lamp Type	CCT
4-foot medium bipin	≤4,500 K
	>4,500 K
2-foot U-shaped	≤4,500 K
	>4,500 K
8-foot single pin slimline	≤4,500 K
	>4,500 K
8-foot recessed double contact high output	≤4,500 K
	>4,500 K
4-foot T5 miniature bipin standard output	≤4,500 K
	>4,500 K
4-foot T5 miniature bipin high output	≤4,500 K
	>4,500 K

5.3.2 Baseline Lamps

For each representative product class, DOE selects baseline lamps that are typically the most common, least efficacious lamps that meet existing standards. To identify baseline lamps, DOE reviews product offerings in catalogs, shipment information, and manufacturer feedback obtained during interviews. Common lamp types are selected based on characteristics such as diameter, wattage, CCT, and lifetime. DOE used rated efficacy^b to evaluate baseline lamps for this analysis.

DOE selected the minimally compliant products on the market that just met the existing standard as baseline lamps. For representative product classes in which there were no commercially available lamps at the existing standard level, DOE modeled baseline lamps. Specifically, baselines were modeled for the 8-foot RDC HO, T5 MiniBP SO, and T5 MiniBP HO product classes. DOE assumed the modeled baseline lamps would have similar characteristics as the most common commercially available lamps in each product class.

Using the ANSI rated wattage of the most common, least efficacious commercially available lamp, DOE back calculated the initial lumen output (at 25 °C) required to develop an efficacy at the existing standard level. To determine lumen depreciation, DOE applied the ratio of mean lumen output to initial lumen output of the most common, least efficacious commercially available lamp to the calculated initial lumen output of the modeled baseline lamp. For the T5 MiniBP SO and T5 MiniBP HO modeled baselines, DOE also calculated the expected increase in lumen output for lamp operation at 35 °C. DOE increased the calculated initial and mean lumen output at 25 °C by 10 percent because when operated at 25 °C, the lumen output of T5 lamps is approximately 10 percent lower than the lumen output of such lamps when operated at 35 °C. DOE assumed the most common lifetime of the product class for the modeled baseline lamps.

^b For GSFLs, the rated efficacy is the initial lumen output published in manufacturer catalogs divided by the American National Standards Institute (ANSI) rated wattage. For lamp types that do not have a defined ANSI rated wattage, DOE utilized the lamp's nominal wattage to calculate rated efficacy.

DOE published a final rule in July 2009 (hereafter the “2009 Lamps Rule”) that adopted standards for certain fluorescent lamps that required compliance in July 2012 (hereafter the “July 2012 standards”). 74 FR 34080 (July 14, 2009). Although these standards are based on performance and do not restrict the sale of specific products, it is difficult for T12 lamps to comply with the July 2012 standards. For products classes that may include both T12 and T8 products (the 4-foot MBP, 8-foot SP slimline, and 8-foot RDC HO product classes), DOE chose baseline lamps with T8 diameters.

Based on DOE’s review of the market, a limited number of T12 lamps are currently available that comply with the July 2012 standards. DOE only considers non-exempt, standards-compliant lamps in the engineering analysis. Further, it will be difficult for T12 electronic ballasts to comply with the standards adopted by the 2011 Ballast Rule,^c thus further shifting the market away from T12 lamps. Additionally, historical shipments of most T12 lamps have been decreasing steadily and manufacturer feedback suggests that shipments will likely to continue to do so. For these reasons, DOE concluded that a T12 lamp is not representative of a commonly available lamp type and subsequently elected not to analyze a T12 baseline.

A summary of the GSFL baseline lamps is shown in Table 5.3.2.

Table 5.3.2 GSFL Baseline Lamps

Representative Product Class	Lamp Diameter	Nominal Wattage	ANSI Rated Wattage	Rated Efficacy**	Initial Lumen Output†	Mean Lumen Output‡	Life (IS)	Life (PS)	CRI
		W	W	lm/W	lm	lm	hr	hr	
4-foot MBP	T8	32	32.5	89.2	2,900	2,725	24,000	40,000	83
8-foot SP slimline	T8	59	60.1	96.5	5,800	5,220	24,000	-	80
8-foot RDC HO	T8	86	84.0	92.0	7,728	7,342	18,000	-	-
4-foot T5 MiniBP SO*	T5	28	27.8	86.0	2,391	2,223	-	30,000	-
4-foot T5 MiniBP HO*	T5	54	53.8	76.0	4,089	3,884	-	25,000	-

* 4-foot T5 MiniBP SO and HO rated efficacy, initial lumen output, and mean lumen output given at 25 °C.

** Rated efficacy is catalog initial lumen output divided by the ANSI rated wattage.

† Initial lumen output is a lamp’s light output after 100 hours of seasoning.

‡ Mean lumen output is a measure of light output midway through the rated life of a lamp.

^c The final rule amending energy conservation standards for fluorescent lamp ballasts published in 2011 with a compliance date of November 14, 2014. 76 FR 70548 (Nov. 14, 2011). The full text and all related documents of the 2011 Ballast Rule can be found on regulations.gov, docket number EERE-2007-BT-STD-0016 at www.regulations.gov/#!docketDetail;D=EERE-2007-BT-STD-0016.

5.3.3 More Efficacious Substitutes

After choosing a baseline lamp for each representative product class, DOE identifies more efficacious substitutes. Similar to the selection of baseline lamps, DOE used the rated efficacy to evaluate more efficacious replacement lamps in its analysis. DOE also sought to keep other characteristics of substitute lamps as similar as possible to the baseline lamps, such as rated life, color rendering index (CRI), and CCT.

Higher efficacies are achieved through a variety of technologies. As discussed in the screening analysis (chapter 4 of this TSD), DOE considered commercially available GSFLs that use highly emissive electrode coatings, higher efficiency lamp fill gas composition, higher efficiency phosphors, glass coatings, or higher efficiency lamp diameter to achieve more efficacious lamp designs. These technologies are discussed in further detail in chapter 3 of this TSD. DOE utilized a database of commercially available lamps when identifying the more efficacious substitutes.

5.3.4 Efficacy Levels

After identifying more efficacious substitutes for each of the baseline lamps, DOE develops ELs based on the consideration of several factors, including: (1) the design options associated with the specific lamps being studied (*e.g.*, grades of phosphor); (2) the ability of lamps across wattages to comply with the standard level of a given product class; and (3) the maximum technologically feasible (“max tech”) level. Although fluorescent lamps are a component of a system that often includes ballasts and fixtures, DOE based its ELs only on lamp performance because GSFLs are the subject of this rulemaking. DOE acknowledges, however, that the energy consumption of fluorescent lamps is related to the ballast on which they operate. Therefore, DOE pairs each lamp with an appropriate ballast to better approximate real-world conditions. Lamp-and-ballast systems are discussed in more detail in section 5.3.5.

When selecting ELs, DOE only considered ELs at which a full wattage version of the lamp type was available because reduced wattage lamps have limited utility. Manufacturer feedback indicated that reduced wattage lamps have problems starting in cold temperature applications below 60-65 °F, and may also exhibit striations in this temperature range. In manufacturer interviews, it was noted that striations remain an issue for reduced wattage lamps because not all ballasts contain striation control circuitry, and those that are equipped with striation control circuitry do not completely eliminate striation. Further, manufacturers identified issues with dimming reduced wattage lamps indicating that these lamps dim unreliably in certain applications. Manufacturers noted that problems encountered with dimming linear fluorescent lamps, including lamp starting, striations, and dropout, are exacerbated by the use of krypton in reduced wattage lamps.

To determine appropriate ELs, DOE used a database of commercially available lamps, when possible, and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) to determine appropriate ELs. DOE found that efficacies of lamps when reported for certification purposes can vary from catalog rated values. Therefore, DOE also analyzed publicly available data submitted to DOE by manufacturers to demonstrate compliance

with existing energy conservation standards.^d DOE found certification data for only 68 percent of covered GSFL products compliant (based on catalog efficacy) with the July 2012 standards. Because the certification data did not represent a comprehensive dataset of covered products on which to base an engineering analysis, DOE utilized catalog data to identify baseline products and develop initial efficacy levels. This approach ensured consideration of all available products. DOE then used available certification data to adjust the initial efficacy levels, if necessary, thereby ensuring that the proposed levels can be met based on the certification values submitted by manufacturers to demonstrate compliance with standards. For more information on specific adjustments to the ELs, see section 5.3.6.

5.3.5 GSFL Systems

Because fluorescent lamps operate on a ballast in practice, DOE analyzed lamp-and-ballast systems in the engineering analysis. DOE believes that pairing a lamp with a ballast more accurately captures real-world energy use and light output.

DOE is aware that lumen package is an important consideration for consumers. If consumers do not have the option to purchase substitute lamp-and-ballast systems with similar lumen packages, a modification in the lighting design of their space (*e.g.*, change in fixture spacing) may be required to maintain a similar light output. In assessing light output of the representative systems, DOE made a distinction between mean and initial lumen output. Consistent with industry consensus on efficacy measurements, DOE requires initial lumen output be used to determine lamp efficacy in its test procedures for GSFLs. Therefore, as stated in section 5.3.2, DOE used catalog initial lumen output to calculate efficacy when determining ELs. However, the light output of a lamp decreases over time. To account for this real-world depreciation in lumens, DOE analyzed more efficacious systems that maintain mean lumen output within 10 percent of the baseline, when possible. Mean lumen output is a measure of light output midway through the rated life of a lamp, and a 10 percent change is a common parameter used by lighting designers to specify acceptable substitute products on the basis of light output.

In the LCC analysis, DOE considers lamp purchase events, or events that cause a consumer to purchase a new lamp. For GSFLs, DOE determined that consumers may purchase a new lamp to operate on an existing ballast or purchase a new lamp as part of a new lamp-and-ballast system. Therefore, DOE considered two different scenarios in the engineering analysis. For both scenarios, DOE only selected replacement systems that do not have higher energy consumption than the baseline system. The NIA allows consumers to make other choices, including selecting an alternative lighting technology. See chapter 9 of this TSD for more detail.

For the first event, known as the lamp replacement scenario, DOE selects more efficacious full wattage and reduced wattage replacement lamps that can operate on the installed ballast. For the second event, known as the lamp-and-ballast replacement scenario, DOE selects lamps that have the same or lower wattage compared to the baseline lamp and also selects a new ballast with potentially different performance characteristics, such as ballast factor (BF) or

^d The publicly available compliance information for GSFLs can be found in DOE's Compliance Certification Database available here: www.regulations.doe.gov/certification-data/.

ballast luminous efficiency (BLE). For example, a lamp-and-ballast system with a more efficacious, similar wattage lamp and lower BF ballast will consume less energy while maintaining similar light output compared to the baseline system.

For both substitution scenarios, DOE determined energy consumption by calculating the system input power of the lamp-and-ballast system. The system input power represents the energy consumption rate of both the lamp and ballast, and therefore is greater than the rated power of the lamp alone. In addition to the rated lamp power, the system power is also affected by the number of lamps operated per ballast, type of ballast used (*i.e.*, electronic or magnetic), starting method, and the BF of that ballast.

The following sections discuss in more detail how DOE selected ballasts for each representative lamp-and-ballast pairing.

5.3.5.1 Ballast Selection

DOE used manufacturer feedback and information provided in the 2011 Ballast Rule to determine which fluorescent lamp ballasts were representative of the market. DOE first identified the most common number of lamps operated per ballast, the most common starting methods by ballast type, and the most common mode of operation (*i.e.*, electronic or magnetic). DOE then selected an appropriate ballast for each representative lamp-and-ballast pairing.

Representative Ballast Types

Fluorescent lamp ballasts can often operate different numbers of lamps; some ballast types can operate up to six individual lamps. In the 2011 Ballast Rule, DOE identified the number of lamps most commonly operated by fluorescent ballasts. In that rule, DOE estimated that approximately 40 percent of ballasts that operate F32T8^e lamps (the most common 4-foot MBP lamp) are two-lamp ballasts, 30 percent are four-lamp ballasts, 20 percent are three-lamp ballasts, and 10 percent are one-lamp ballasts. Thus, DOE directly analyzed both two-lamp and four-lamp ballasts that operate 4-foot MBP lamps. For ballasts designed to operate 8-foot SP slimline, 8-foot RDC HO, 4-foot T5 MiniBP HO, and 4-foot T5 MiniBP SO lamps, DOE estimated that the majority are two-lamp ballasts and therefore concentrated its analytical effort on two-lamp ballasts for these lamp types. In this NOPR analysis, to most accurately represent the market, DOE chose to analyze ballasts that operate the same number of lamps as those analyzed in the 2011 Ballast Rule. Manufacturer feedback confirmed that these are the most common products.

In addition to operating different numbers of lamps, fluorescent lamp ballasts can also have different starting methods. The 2011 Ballast Rule identified the most common starting methods for each ballast type. In the 2011 Ballast Rule, for ballasts that operate 4-foot MBP

^e Lamp types are identified by a series of letters and numbers. The letter “F” designates a fluorescent lamp. The two-digit number following identifies either the nominal lamp wattage for 4-foot lamps or the lamp length in inches for 8-foot lamps. The two-digit number is then followed by the letter “T” for tubular and the lamp diameter in eighths of an inch.

lamps, DOE directly analyzed the instant start (IS)/rapid start (RS)^f product class and programmed start (PS) product class in the commercial and industrial sectors, and the IS/RS product class in the residential sector. DOE found that the majority of T8 ballasts were IS and therefore analyzed an IS T8 representative ballast type for 4-foot MBP lamps, 8-foot SP slimline lamps,^g and 8-foot RDC HO lamps. DOE also directly analyzed PS ballasts for 4-foot MBP lamps due to their increasing market share. For ballasts that operate 4-foot T5 MiniBP SO lamps and 4-foot T5 MiniBP HO lamps, DOE directly analyzed PS ballasts, which represent the vast majority of ballasts for these lamp types. In this NOPR analysis, to accurately reflect the market, DOE selected ballasts with the same starting methods analyzed in the 2011 Ballast Rule. Manufacturer feedback confirmed that these starting method combinations are the most common for each lamp type.

As noted in the 2011 Ballast Rule, it is difficult for magnetic ballasts to comply with the standard levels adopted by the previous final rule amending fluorescent lamp ballast energy conservation standards (65 FR 56740 [Sept. 19, 2000]) and the standards established by the Energy Policy Act of 2005 (Pub. L. 109-58). As a result, electronic ballasts make up the majority of ballasts available on the market. Standards adopted by the 2011 Ballast Rule, which require compliance in November 2014, will effectively eliminate any remaining magnetic ballasts on the market. Therefore, DOE analyzes only electronic ballasts in this NOPR analysis.

Table 5.3.3 shows the representative lamp-and-ballast system pairings that DOE analyzed in this NOPR analysis.

Table 5.3.3 Representative Lamp-and-Ballast System Pairings

Lamp Type	Ballast Type
4-foot MBP	2-lamp IS, electronic
	2-lamp PS, electronic
	4-lamp IS, electronic
	4-lamp PS, electronic
	2-lamp IS for residential use, electronic
8-foot SP slimline	2-lamp IS, electronic
8-foot RDC HO	2-lamp IS, electronic
4-foot T5 MiniBP SO	2-lamp PS, electronic
4-foot T5 MiniBP HO	2-lamp PS, electronic

^f Although IS and RS are different starting method technologies, DOE determined in the 2011 Ballast Rule that IS and RS ballasts were commonly used as substitutes for each other, and therefore separate product classes were not established. See chapter 3 of the TSD for the 2011 Ballast Rule for more information available on regulations.gov, docket number EERE-2007-BT-STD-0016 at www.regulations.gov/#!docketDetail;D=EERE-2007-BT-STD-0016.

^g Instant start is the only starting method compatible with 8-foot slimline lamps.

Ballast Models Used in Representative Lamp-And-Ballast Pairings

After determining the representative lamp-and-ballast system pairings, DOE selected specific ballast models to use in each system analyzed. DOE utilized the commercially available ballast models analyzed and tested for the 2011 Ballast Rule^h when possible to pair with the representative lamp units. DOE believed this to be an accurate representation of ballasts currently available on the market, and the most complete source of ballast efficiency in terms of the BLE metric, which is defined as total lamp arc power divided by ballast input power. In some cases, DOE utilized newer ballasts that were not tested for the 2011 Ballast Rule in order to consider additional BF options.

For the lamp replacement scenario, DOE selected a ballast that represents the product that is most likely to be installed in 2014. DOE utilized the representative units associated with the efficiency levels adopted in the 2011 Ballast Rule or ballasts with comparable performance characteristics so as to best represent the market in terms of efficiency. For example, because DOE adopted EL 3 for ballasts that operate 4-foot MBP lamps, DOE used the ballast performance characteristics for the representative units at EL 3 to pair with 4-foot MBP lamps in the lamp replacement scenario.

As stated previously, DOE tried to select lamp-and-ballast systems that maintained mean lumen output within 10 percent of the baseline system, when possible. However, in some cases DOE was unable to pair reduced wattage lamps (*e.g.*, 25 W 4-foot MBP lamp) with ballasts that would provide a system mean lumen output within 10 percent of the baseline while still achieving energy savings. Reduced wattage lamps typically have lower lumen output compared to full wattage versions. In order to achieve system mean lumen output within 10 percent of a full wattage baseline, some reduced wattage lamps require the use of a high BF ballast. However this combination could increase the overall energy consumption of the system relative to the baseline. In such cases, priority was given to achieving energy savings over maintaining lumen output as only systems that do not increase energy consumption are considered in the engineering analysis.

DOE also considered the replacement of more efficacious full wattage lamps for the lamp replacement scenario in the NOPR analysis. DOE added this replacement option because DOE believes that installing a more efficacious, full wattage lamp on an existing ballast is a possible replacement scenario for consumers. DOE notes that such systems would result in the same energy consumption as the baseline system but with increased lumen output.

For the lamp-and-ballast replacement scenario, DOE selected ballast models using a different methodology. For this scenario, DOE selected a higher efficiency (based on BLE) ballast at the baseline than selected in the lamp replacement scenario because it was assumed that a newly purchased ballast would likely be more efficient than an installed ballast. For the representative units at higher ELs, DOE selected a ballast with a lower BF than the normal BF baseline ballast, when possible, in order to further improve energy savings. Thus, at each EL above the baseline, DOE identified a commercially available ballast that had the lowest BF

^h The ballast test data from the 2011 Ballast Rule is publicly available on at www.regulations.gov/#!documentDetail;D=EERE-2007-BT-STD-0016-0054.

possible while still maintaining system mean lumen output within 10 percent of the baseline system. When multiple ballasts with the same BF existed, DOE selected the most efficient ballast based on BLE as this was considered to be the most likely substitute in a ballast replacement scenario designed to achieve energy savings. In some cases, DOE was unable to pair a reduced wattage representative unit with a ballast that would provide a system mean lumen output within 10 percent of the baseline while still achieving energy savings (*e.g.*, 25 W 4-foot MBP lamp). As stated previously, priority was given to energy savings over maintaining lumen output as only systems that do not increase energy consumption relative to the baseline are considered in the engineering analysis.

Some lamp-and-ballast replacement systems considered maintain light output within 10 percent of the baseline system but do not save energy. For these systems, DOE added additional replacement options in the NOPR in response to feedback from stakeholders that some consumers would prioritize energy savings over increasing or maintaining light output. Thus in the NOPR analysis, DOE added the replacement option in which the consumer could prioritize energy savings by selecting a lamp-and-ballast system that reduced lumen output by more than 10 percent but also reduced energy consumption. Therefore, for certain lamp-and-ballast replacement scenarios, two ballast selections may exist: 1) a ballast that maintains system mean lumen output within 10 percent of the baseline; and 2) a ballast that achieves energy savings but does not maintain system mean lumen output within 10 percent of the baseline. In some cases this replacement option resulted in mean lumen output up to 17 percent less than the baseline system mean lumen output. (See section 5.3.6 for complete engineering results.) DOE only added this option if ballasts with the required lower BF were commercially available. Thus, it also remains possible for certain scenarios to not result in energy savings if a lower BF ballast or reduced wattage lamp is not available (*e.g.*, 8-foot RDC HO product class).

5.3.5.2 System Input Power Calculation

After selecting ballasts to pair with the representative units at each EL, DOE then calculated the system input power. The system input power depends on both the total lamp arc power operated by the ballast and the ballast's efficiency, or BLE. DOE first calculated the total lamp arc power of the system by multiplying the catalog BF, number of lamps operated by the ballast, and the high frequency reference lamp arc power. Because DOE only analyzed electronic ballasts in this rulemaking, all lamp-and-ballast systems were high frequency. The high frequency reference lamp arc powers are shown in Table 5.3.4. If a high frequency reference arc power was not available for a specific lamp type, DOE used the nominal wattage.

Table 5.3.4 High Frequency Reference Lamp Arc Powers

Lamp Type	Nominal Wattage	High Frequency Reference Lamp Arc Power
T8 4-foot MBP	32	29.0
	28	26.0
	25	24.2
T8 8-foot SP slimline	59	57.0
	54	N/A
	50	N/A
T8 8-foot RDC HO	86	84.0
T5 MiniBP SO	28	27.8
	26	N/A
	25	N/A
T5 MiniBP HO	54	53.8
	49	N/A
	47	N/A

For ballasts paired with full wattage lamps, DOE was able to use the publicly available tested BLE value for most of the selected ballast model to determine the system input power. Using the calculated total lamp arc power and tested BLE value of the ballast model, DOE then calculated the system input power, equivalent to ballast input power, using Eq. 5.1. This process was repeated for each full wattage lamp-and-ballast system pairing. For newer ballasts that were selected to be paired with lamps in this analysis but were not tested for the 2011 Ballast Rule, DOE determined BLE using catalog ballast efficacy factorⁱ (BEF). DOE then used the calculated total lamp arc power and converted BLE value to determine the system input power using Eq. 5.1.

$$BLE = \frac{\text{Total Lamp Arc Power}}{\text{Ballast Input Power}} * 100 * \beta$$

Eq. 5.1

Where:

$\beta = 1.0$ for high frequency ballasts

Because the 2011 Ballast Rule did not test ballasts when operating reduced wattage lamps, DOE had to determine the expected BLE using the test results of the ballast operating full wattage lamps and the known power-efficiency relationship of ballasts. Similarly, for ballasts not tested in the 2011 Ballast Rule, DOE used the catalog values of ballasts operating full wattage lamps to determine the expected BLE when operating reduced wattage lamps. In the 2011 Ballast Rule, DOE developed a power law equation to model the trend between total lamp arc power and average BLE. The power law equation followed the form:

ⁱ Ballast efficacy factor is equal to relative light output divided by input power.

$$BLE = \frac{A}{1 + B * power^{-C}}$$

Eq. 5.2

Where:

power = total lamp arc power

Similar to the full wattage system, DOE first calculated the total lamp arc power of the reduced wattage lamp-and-ballast system. DOE assumed that BF does not change when operating reduced wattage lamps and therefore used the catalog BF of the ballast when operating full wattage lamps to calculate the total lamp arc power for both full wattage and reduced wattage systems.

In general, as lamp arc power increases or decreases, BLE increases or decreases as well.^j In the 2011 Ballast Rule, DOE defined this relationship using the equation above. In this rulemaking, DOE assumed that this relationship holds true for individual ballasts. Therefore, DOE assumed that an individual ballast operating full wattage lamps would have the same coefficient *B* when operating reduced wattage lamps. Using this assumption, DOE calculated the selected ballast model's coefficient *B* when operating full wattage lamps using the tested BLE value from the 2011 Ballast Rule or calculated BLE value based on catalog information (*i.e.*, BEF) for ballasts not tested, the calculated total lamp arc power at full wattage, and the appropriate exponent *C*, which is dependent on the ballast starting method.^k The coefficient *A* was assumed to be one.^l DOE was then able to calculate the new BLE when operating reduced wattage lamps by using the total lamp arc power when operating reduced wattage lamps and keeping the coefficient *B*, the exponent *C*, and the coefficient *A* the same. Given this expected BLE and total lamp arc power calculated in the previous steps, DOE determined the system input power of the reduced wattage lamp-and-ballast system using Eq. 5.2. This process was repeated for each unique reduced wattage lamp-and-ballast pairing.

5.3.6 Engineering Results by Representative Product Classes

The following sections discuss the lamp models DOE is considering for the five representative product classes considered in the engineering analysis.

^j For more information on the power versus efficiency relationship of ballasts, please see TSD chapter 3 of the 2011 Ballast Rule – available on regulations.gov, docket number EERE-2007-BT-STD-0016, at www.regulations.gov/#!docketDetail;D=EERE-2007-BT-STD-0016.

^k The exponent *C* was found to be 0.25 for IS/RS ballasts and 0.37 for PS ballasts in the 2011 Ballast Rule. See chapter 5 of the 2011 Ballast Rule TSD, available on regulations.gov, docket number EERE-2007-BT-STD-0016, at www.regulations.gov/#!docketDetail;D=EERE-2007-BT-STD-0016.

^l The coefficient *A* was used as an adjustment factor for testing variation when developing efficiency levels in the 2011 Ballast Rule. In this rulemaking, *A* was assumed to be one as no adjustments were made to the ballast test data used in the calculation.

5.3.6.1 Four-Foot MBP GSFLs with CCTs $\leq 4,500$ K

Baseline Lamps

DOE selected baseline lamps as reference points from which to measure changes resulting from potential energy conservation standards. As discussed in section 5.2, a baseline lamp is typically the most common, least efficacious lamp sold in a given product class. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit.

DOE considered a number of criteria when selecting which commercially available lamp would serve as a baseline. The 4-foot MBP lamps have traditionally been manufactured in both T8 and T12 diameters. DOE selected a T8 4-foot MBP as a baseline based on its high shipment volume (see section 5.3.2 for an additional discussion of why DOE did not analyze a T12 baseline). In 2011, T8 lamps represented 74 percent of the 4-foot MBP shipments, while shipments of T12 lamps represented 26 percent.

Through a review of product offerings and manufacturer feedback, DOE determined that 32 W is the most common wattage for T8 4-foot MBP lamps by a substantial margin. For the 32 W T8 4-foot MBP baseline lamp, DOE identified typical performance characteristics. DOE selected a baseline lamp that uses basic 800 series rare earth phosphor. These lamps typically have a CRI of 80 to 86. For all baseline lamps and more efficacious lamp designs, DOE analyzed fluorescent lamps with a CCT of 4,100 K because it represents the highest volume CCT for this category of lamps. As mentioned in section 5.3.5, DOE chose to pair representative lamps with both an IS ballast and a PS ballast. The typical lifetime for the baseline lamp is 24,000 hours when paired with an IS ballast and 40,000 hours when paired with a PS ballast.

Although DOE is analyzing 4-foot MBP lamps in the residential sector, DOE did not identify a baseline lamp specific to the residential sector. After reviewing available catalog information, DOE found that the T8 4-foot MBP lamps sold in the residential sector share similar characteristics as those offered in the commercial and industrial sectors. Therefore, DOE did not analyze a separate baseline for the residential sector.

Typically, a baseline product is a unit that just meets the existing energy conservation standard for the product (89 lm/W for this product class). DOE identified a lamp with an efficacy of 89.2 lm/W to be the most common, least efficacious 32 W T8 4-foot MBP lamp available that just meets existing standards. This lamp also represented the lowest efficacy of standards-compliant lamps in this product class. Table 5.3.5 lists the characteristics of the 32 W T8 4-foot MBP baseline lamp.

Table 5.3.5 Baseline Lamp for the 4-foot MBP Representative Product Class

Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life (IS)	Rated Life (PS)	CRI	CCT
	W	W	lm/W	lm	lm	hr	hr		K
T8	32	32.5	89.2	2,900	2,725	24,000	40,000	83	4,100

Efficacy Levels and More Efficacious Substitutes

In general terms, DOE based its ELs on the design options described below. Because utilizing higher efficiency phosphors is the most common method to achieve higher efficacies, DOE describes the phosphor technology associated with each EL:

EL 1: This level requires the use of an improved 800 series full wattage (32 W) T8 lamp in which the phosphor mix and/or coating is enhanced to increase efficacy.

EL 2: This level represents max tech, the most efficacious products available today. The 32 W T8 lamps use premium 800 series rare earth phosphor and are referred to as high lumen products. Reduced wattage 25 W T8 and 28 W T8 lamps that produce similar lumen outputs as the baseline unit also meet this EL.

Figure 5.3.1 illustrates the two initial ELs on a plot with the representative lamps. A line at 89 lm/W denotes the existing energy conservation standard (the July 2012 standards). The square box identifies the baseline lamp. The plot also shows the more efficacious substitutes that DOE considered as replacements. Some of the representative units shown on the plot are at the same wattage as the baseline, but have a higher efficacy; others have a combination of lower wattage and higher efficacy.

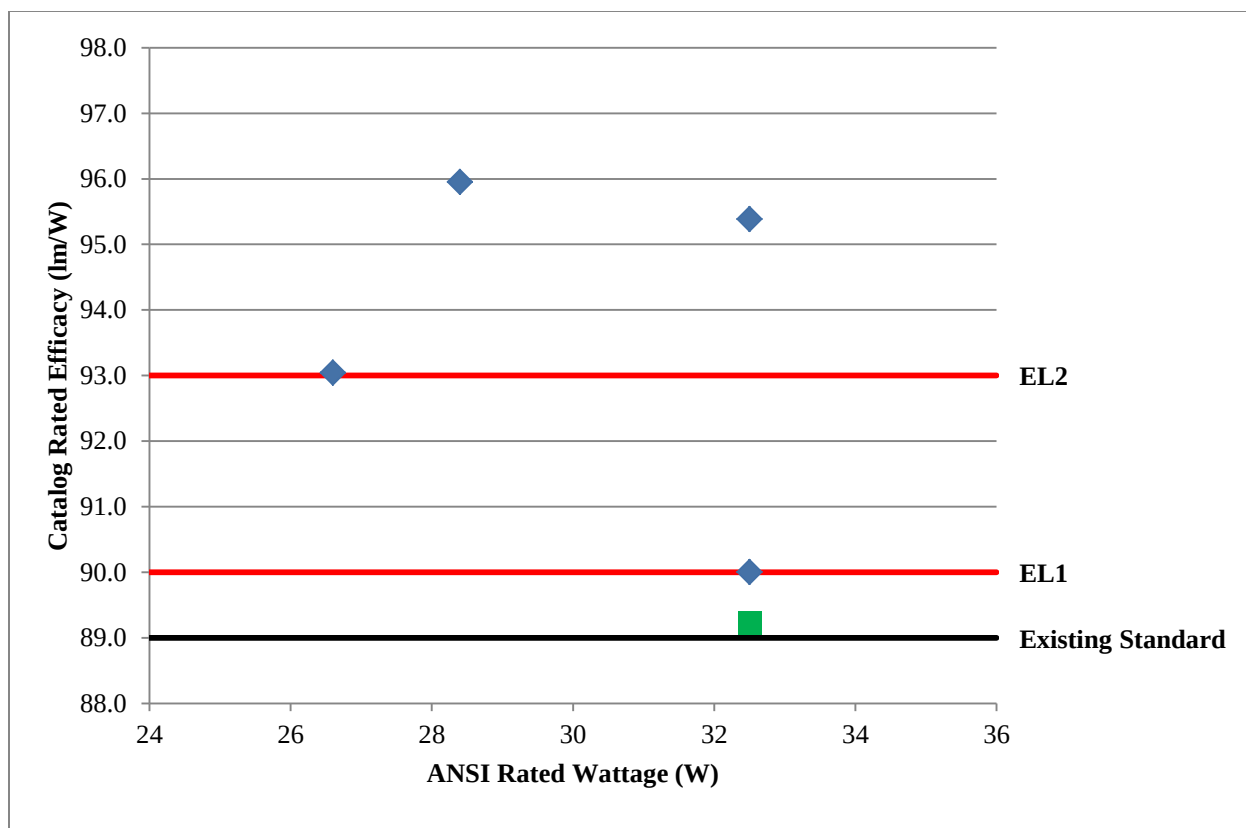


Figure 5.3.1 Efficacy Levels for 4-foot MBP GSFLs with CCTs $\leq$ 4,500 K

Table 5.3.6 provides detailed information on the 4-foot MBP representative lamps used in the engineering analysis and subsequent analyses.

Table 5.3.6 4-foot MBP Representative Lamps

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life (IS)	Rated Life (PS)	CRI
		W	W	lm/W	lm	lm	hr	hr	
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	40,000	83
1	T8	32	32.5	90.0	2,925	2,770	21,000	30,000	85
2	T8	25	26.6	93.0	2,475	2,350	24,000	40,000	85
2	T8	32	32.5	95.4	3,100	2,945	24,000	40,000	85
2	T8	28	28.4	96.0	2,725	2,560	24,000	40,000	85

As discussed above, DOE used commercially available lamps, when possible, and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) to determine each initial EL. However, to establish the minimum efficacy requirements for each EL, DOE also considered data submitted to DOE by manufacturers to demonstrate compliance

with existing energy conservation standards. DOE determined if any adjustments were necessary to the initial ELs to account for compliance efficacies of representative units and/or equivalent lamps. DOE considered equivalent lamps to be manufacturer-identified cross references of the representative units or lamps deemed to have equivalent characteristics.

By examining publicly available compliance reports, DOE found that approximately 75 percent of available 4-foot MBP lamps had compliance information. Using this information, DOE determined that the representative unit and/or equivalent lamps complied with EL 1. However, based on this information, DOE found that an adjustment to EL 2 was necessary. DOE adjusted EL 2 from 93.0 lm/W to 92.4 lm/W based on certification data available for the 25 W reduced wattage lamps. Figure 5.3.2 summarizes all available compliance information by lamp design (*i.e.*, basic 800 series, improved 800 series, high lumen, reduced wattage, and other^m) and the resulting ELs.

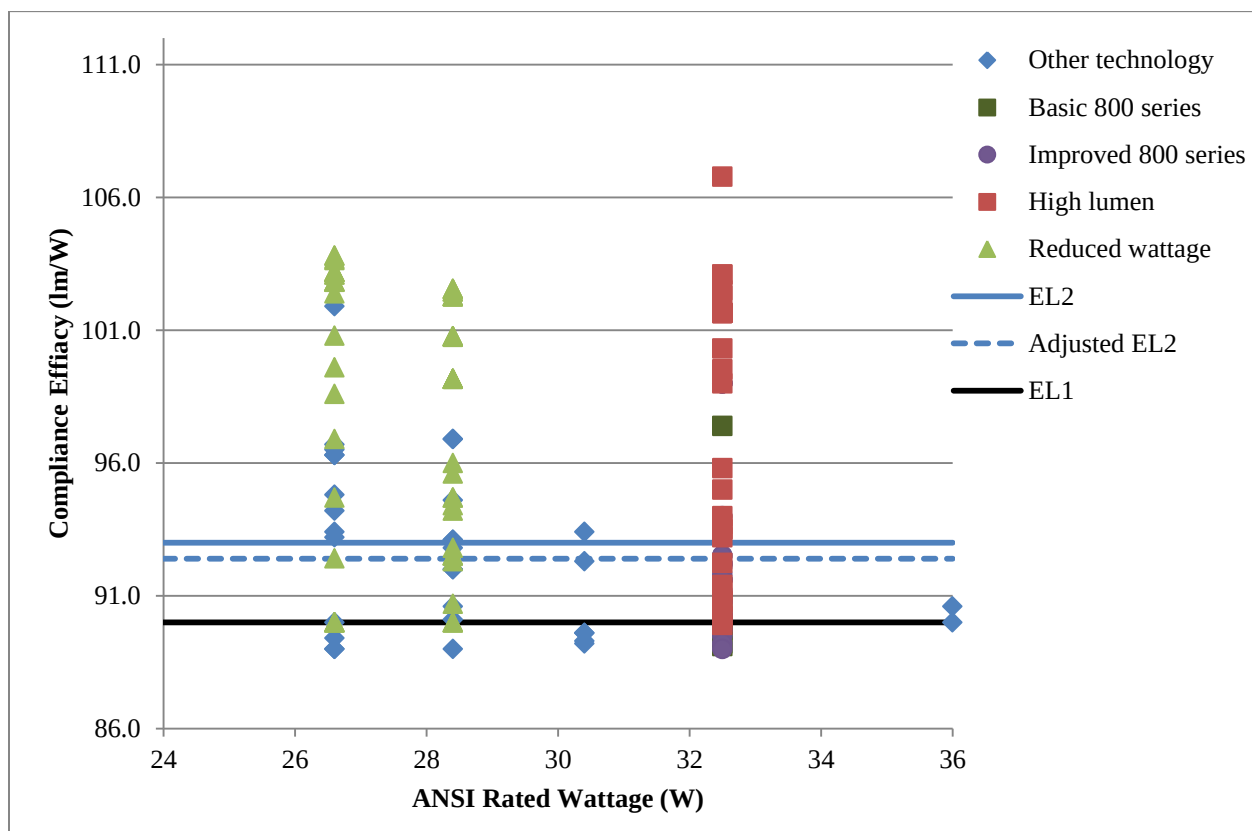


Figure 5.3.2 All Compliance Report Data for 4-foot MBP GSFLs with CCTs $\leq$ 4,500 K

^m Lamps labeled as “other” designate lamp designs that are not representative of the most common characteristics identified.

Table 5.3.7 summarizes the final efficacy requirements at EL 1 and EL 2.

Table 5.3.7 EL 1 and EL 2 for 4-foot MBP GSFLs with CCTs $\leq$ 4,500 K

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	90.0
EL 2	92.4

Engineering Summary

The first set of engineering results present the lamp replacement scenarios for the 4-foot MBP representative product class. In this scenario, energy savings are achieved through the use of higher efficacy, reduced wattage lamps. Higher efficacy, full wattage lamps are also analyzed, however, no energy savings are achieved for these replacements. As stated in section 5.3.4, replacement lamp options were selected so that the system mean lumen output was within 10 percent of the baseline, when possible. If it was not possible to identify a lamp-and-ballast replacement that maintained the 10 percent mean lumen output criterion, such as the 25 W 4-foot MBP lamp, DOE prioritized energy savings and analyzed a lamp-and-ballast system that reduced light output by more than 10 percent but saved energy relative to the baseline system.

Table 5.3.8 presents the engineering analysis results for two-lamp 4-foot MBP IS systems operating in the commercial and industrial sectors. Table 5.3.9 presents the engineering analysis results for two-lamp 4-foot MBP PS systems operating in the commercial and industrial sectors. Table 5.3.10 presents the engineering analysis results for four-lamp 4-foot MBP IS systems operating in the commercial and industrial sectors. Table 5.3.11 presents the engineering analysis results for four-lamp 4-foot MBP PS systems operating in the commercial and industrial sectors. Table 5.3.12 presents the engineering analysis results for two-lamp 4-foot MBP IS systems operating in the residential sector.

Table 5.3.8 Lamp Replacement Engineering Analysis for a Two-Lamp Instant Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	2	IS	0.88	56.0	91.2	5,104	4,796
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	2	IS	0.88	56.0	91.2	5,148	4,875
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	2	IS	0.88	46.9	90.9	4,356	4,136
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	2	IS	0.88	56.0	91.2	5,456	5,183
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	2	IS	0.88	50.3	91.0	4,796	4,558

Table 5.3.9 Lamp Replacement Engineering Analysis for a Two-Lamp Programmed Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	2	PS	0.88	56.0	91.2	5,104	4,796
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	2	PS	0.88	56.0	91.2	5,148	4,875
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	2	PS	0.88	47.0	90.6	4,356	4,136
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	2	PS	0.88	56.0	91.2	5,456	5,183
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	2	PS	0.88	50.4	90.9	4,796	4,558

Table 5.3.10 Lamp Replacement Engineering Analysis for a Four-Lamp Instant Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	4	IS	0.87	108.0	93.4	10,092	9,483
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	4	IS	0.87	108.0	93.4	10,179	9,640
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	4	IS	0.87	90.4	93.2	8,613	8,178
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	4	IS	0.87	108.0	93.4	10,788	10,249
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	4	IS	0.87	97.0	93.3	9,483	9,013

Table 5.3.11 Lamp Replacement Engineering Analysis for a Four-Lamp Programmed Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	4	PS	0.89	111.0	93.0	10,324	9,701
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	4	PS	0.89	111.0	93.0	10,413	9,861
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	4	PS	0.89	93.1	92.5	8,811	8,366
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	4	PS	0.89	111.0	93.0	11,036	10,484
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	4	PS	0.89	99.8	92.7	9,701	9,220

Table 5.3.12 Lamp Replacement Engineering Analysis for a Two-Lamp Instant Start 32 W T8, 4,100 K System in the Residential Sector

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	2	IS	0.87	56.5	89.3	5,046	4,742
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	2	IS	0.87	56.5	89.3	5,090	4,820
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	2	IS	0.87	47.4	88.8	4,307	4,089
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	2	IS	0.87	56.5	89.3	5,394	5,124
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	2	IS	0.87	50.8	89.0	4,742	4,507

The next set of engineering results present the lamp-and-ballast replacement scenarios for the 4-foot MBP representative product class. For this scenario, as stated in section 5.3.5, the ballast with the lowest possible BF was selected that still maintained system mean lumen output within 10 percent of the baseline system. If it was not possible to identify a lamp-and-ballast replacement that maintained the 10 percent mean lumen output criterion, DOE prioritized energy savings and analyzed a lamp-and-ballast system that reduced light output by more than 10 percent but saved energy relative to the baseline system. DOE also added the replacement option in which the consumer could prioritize energy savings by selecting a lamp-and-ballast system that reduced lumen output by more than 10 percent but also reduced energy consumption. DOE only added this option if ballasts with the required lower BF were commercially available.

Table 5.3.13 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 4-foot MBP IS systems in the commercial and industrial sectors. Table 5.3.14 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 4-foot MBP PS systems in the commercial and industrial sectors. Table 5.3.15 presents the engineering analysis results for the replacement lamp-and-ballast combinations for four-lamp 4-foot MBP IS systems in the commercial and industrial sectors. Table 5.3.16 presents the engineering analysis results for the replacement lamp-and-ballast combinations for four-lamp 4-foot MBP PS systems in the commercial and industrial sectors. Table 5.3.17 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 4-foot MBP IS systems in the residential sector.

Table 5.3.13 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Instant Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	2	IS	0.88	55.2	92.4	5,104	4,796
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	2	IS	0.78	49.4	91.6	4,563	4,321
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	2	IS	0.88	46.3	92.1	4,356	4,136
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	2	IS	0.77	48.3	92.4	4,774	4,535
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	2	IS	0.87	48.8	92.8	4,742	4,507

Table 5.3.14 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Programmed Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	2	PS	0.88	56.0	91.2	5,104	4,796
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	2	PS	0.88	56.0	91.2	5,148	4,875
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	2	PS	0.72	47.1	88.7	4,212	3,989
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	2	PS	0.88	47.0	90.6	4,356	4,136
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	2	PS	0.88	56.0	91.2	5,456	5,183
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	2	PS	0.72	47.1	88.7	4,464	4,241
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	2	PS	0.88	50.4	90.9	4,796	4,558

Table 5.3.15 Lamp-and-Ballast Replacement Engineering Analysis for a Four-Lamp Instant Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	4	IS	0.87	107.1	94.2	10,092	9,483
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	4	IS	0.78	96.8	93.4	9,126	8,642
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	4	IS	0.87	89.6	94.0	8,613	8,178
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	4	IS	0.74	93.7	91.6	9,176	8,717
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	4	IS	0.87	96.2	94.1	9,483	9,013

Table 5.3.16 Lamp-and-Ballast Replacement Engineering Analysis for a Four-Lamp Programmed Start 32 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	4	PS	0.89	111.0	93.0	10,324	9,701
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	4	PS	0.87	106.1	95.1	10,179	9,640
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	4	PS	0.89	93.1	92.5	8,811	8,366
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	4	PS	0.87	106.1	95.1	10,788	10,249
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	4	PS	0.87	95.3	94.9	9,483	9,013

Table 5.3.17 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Instant Start 32 W T8, 4,100 K System in the Residential Sector

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	32	32.5	89.2	2,900	2,725	24,000	2	IS	0.87	56.5	89.3	5,046	4,742
EL 1	T8	32	32.5	90.0	2,925	2,770	21,000	2	IS	0.83	53.7	89.7	4,856	4,598
EL 2	T8	25	26.6	93.0	2,475	2,350	24,000	2	IS	0.87	47.4	88.8	4,307	4,089
EL 2	T8	32	32.5	95.4	3,100	2,945	24,000	2	IS	0.83	53.7	89.7	5,146	4,889
EL 2	T8	28	28.4	96.0	2,725	2,590	24,000	2	IS	0.83	48.2	89.5	4,524	4,299

5.3.6.2 Eight-Foot SP Slimline GSFLs with CCTs ≤4,500 K

Baseline Lamps

DOE selected baseline lamps as reference points from which to measure changes resulting from potential energy conservation standards. As discussed in section 5.2, a baseline lamp is typically the most common, least efficacious lamp sold in a given product class. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit.

DOE considered a number of criteria when selecting which commercially available lamp would serve as a baseline. The 8-foot SP slimline lamps have traditionally been manufactured in both T8 and T12 diameters. DOE selected a T8 8-foot SP slimline lamp as a baseline based on manufacturer feedback and recent shipment trends (see section 5.3.2 for an additional discussion of why DOE did not analyze a T12 baseline).

Through a review of product offerings and manufacturer feedback, DOE determined that 59 W is the most common wattage for T8 8-foot SP slimline lamps. For the 59 W T8 8-foot SP slimline lamp, DOE identified typical performance characteristics. DOE selected a baseline lamp that uses less efficient 800 series rare earth phosphor. DOE selected a CCT of 4,100 K because it is the most common CCT for this lamp type. The typical lifetime of the baseline lamp was 24,000 hours when paired with an IS ballast. This lamp type cannot operate on PS ballasts.

Typically, a baseline product is a unit that just meets the existing energy conservation standard for the product (97 lm/W for this product class). DOE identified a lamp with an efficacy of 96.5 lm/W to be the most common, least efficacious 59 W T8 8-foot SP slimline lamp available that just meets existing standards. This lamp also represented the lowest efficacy of standards-compliant lamps in this product class. Table 5.3.18 lists the characteristics of the 59 W 8-foot SP slimline baseline lamp.

Table 5.3.18 Baseline Lamp for the 8-foot SP Slimline Representative Product Class

Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	CRI	CCT
	W	W	lm/W	lm	lm	hr		K
T8	59	60.1	96.5	5,800	5,220	24,000	80	4,100

Efficacy Levels and More Efficacious Substitutes

In general terms, DOE based its ELs on the design options described below. Because utilizing higher efficiency phosphors is the most common method to achieve higher efficacies, DOE describes the phosphor technology associated with each EL:

EL 1: This level represents basic 800 series full wattage (59 W) T8 lamps.

EL 2: This level requires the use of improved 800 series full wattage T8 lamps in which the phosphor mix and/or coating is enhanced to increase efficacy. Reduced wattage lamps, including the 54 W T8 and 50 W T8, that produce similar lumen output as the baseline unit also meet this EL. This level represents max tech, the most efficacious products available today.

Figure 5.3.3 illustrates the initial ELs on a plot with the representative lamps. A line at 97 lm/W denotes the existing energy conservation standard (the July 2012 standards). The square box identifies the baseline lamp. The plot also shows the more efficacious substitutes DOE considered as replacements. Some of the representative units shown on the plot are at the same wattage as the baseline, but have a higher efficacy; others have a combination of lower wattage and higher efficacy.

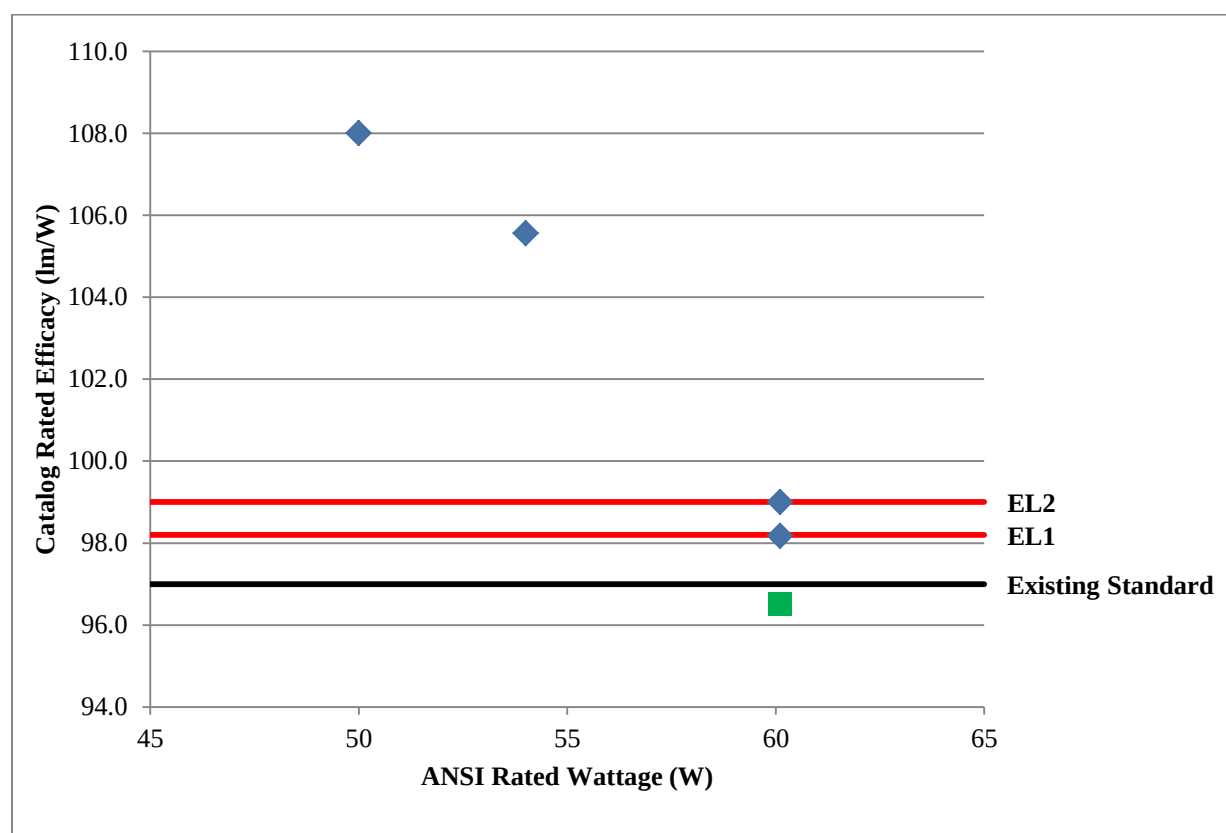


Figure 5.3.3 Efficacy Levels for 8-foot SP Slimline GSFLs with CCTs $\leq$ 4,500 K

Table 5.3.19 provides detailed information on the 8-foot SP slimline representative lamps used in the engineering analysis and subsequent analyses.

Table 5.3.19 8-foot SP Slimline Representative Lamps

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	CRI
		W	W	lm/W	lm	lm	hr	
Baseline	T8	59	60.1	96.5	5,800	5,220	24,000	80
1	T8	59	60.1	98.2	5,900	5,490	24,000	85
2	T8	59	60.1	99.0	5,950	5,650	24,000	85
2	T8	54	54.0	105.6	5,700	5,415	24,000	85
2	T8	50	50.0	108.0	5,400	5,075	24,000	85

As discussed above, DOE used commercially available lamps when possible and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) to determine each initial EL. However, to establish the minimum efficacy requirements for each EL, DOE also considered data submitted to DOE by manufacturers to demonstrate compliance with existing energy conservation standards. DOE determined if any adjustments were necessary to the initial ELs to account for compliance efficacies of representative units and/or equivalent lamps. DOE considered equivalent lamps to be manufacturer-identified cross references of the representative units or lamps deemed to have equivalent characteristics.

By examining publicly available compliance reports, DOE found that approximately 38 percent of available 8-foot SP slimline lamps had compliance information. Using this information, DOE determined that the 59 W representative unit and/or equivalent lamps complied with EL 1. DOE also confirmed that EL 2 was attainable for improved 800 series full wattage lamps and reduced wattage lamps. Thus, based on publicly available compliance information, DOE concluded that no adjustments were necessary to the initial ELs being considered for this product class. Figure 5.3.4 summarizes all available compliance information by lamp design (*i.e.*, basic 800 series, improved 800 series, reduced wattage, and otherⁿ) and the resulting ELs.

ⁿ Lamps labeled as “other” designate lamp designs that are not representative of the most common characteristics identified.

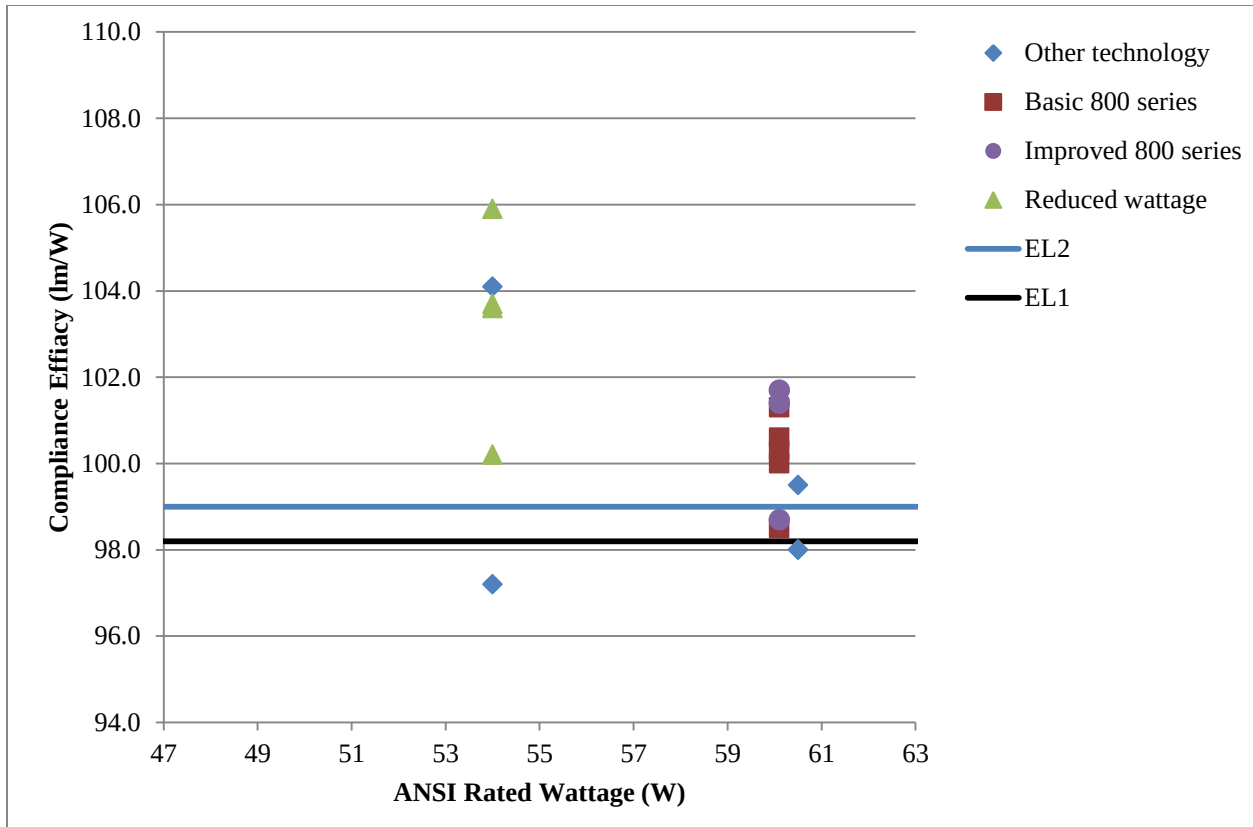


Figure 5.3.4 All Compliance Report Data for 8-foot SP Slimline GSFLs with CCTs $\leq 4,500$ K

Table 5.3.20 summarizes the final efficacy requirements at EL 1 and EL 2.

Table 5.3.20 EL 1 and EL 2 for 8-foot SP Slimline GSFLs with CCTs $\leq 4,500$ K

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	98.2
EL 2	99.0

Engineering Summary

The first set of results present the lamp replacement scenarios for the 8-foot SP slimline representative product class. In this scenario, energy savings are achieved through the use of higher efficacy, reduced wattage lamps. Higher efficacy, full wattage lamps are also analyzed, however, no energy savings are achieved for these replacements. As stated in section 5.3.4, replacement lamp options were selected so that the system mean lumen output was within 10 percent of the baseline, when possible. Table 5.3.21 presents the engineering analysis results for two-lamp 8-foot SP slimline IS systems operating in the commercial and industrial sectors.

Table 5.3.21 Lamp Replacement Engineering Analysis for a Two-Lamp Instant Start 59 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	59	60.1	96.5	5,800	5,220	24,000	2	IS	0.87	106.8	92.9	10,092	9,083
EL 1	T8	59	60.1	98.2	5,900	5,490	24,000	2	IS	0.87	106.8	92.9	10,266	9,553
EL 2	T8	59	60.1	99.0	5,950	5,650	24,000	2	IS	0.87	106.8	92.9	10,353	9,831
EL 2	T8	54	54.0	105.6	5,700	5,415	24,000	2	IS	0.87	101.2	92.8	9,918	9,422
EL 2	T8	50	50.0	108.0	5,400	5,075	24,000	2	IS	0.87	93.9	92.7	9,396	8,831

The next set of engineering results present the lamp-and-ballast replacement scenario for the 8-foot SP slimline representative product class. For this scenario, as stated in section 5.3.5, the ballast with the lowest possible BF was selected that still maintained system mean lumen output within 10 percent of the baseline system. Table 5.3.22 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 8-foot SP slimline IS systems in the commercial and industrial sectors.

Table 5.3.22 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Instant Start 59 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	59	60.1	96.5	5,800	5,220	24,000	2	IS	0.87	105.1	94.3	10,092	9,083
EL 1	T8	59	60.1	98.2	5,900	5,490	24,000	2	IS	0.77	93.9	93.5	9,086	8,455
EL 2	T8	59	60.1	99.0	5,950	5,650	24,000	2	IS	0.77	93.9	93.5	9,163	8,701
EL 2	T8	54	54.0	105.6	5,700	5,415	24,000	2	IS	0.77	89.0	93.4	8,778	8,339
EL 2	T8	50	50.0	108.0	5,400	5,075	24,000	2	IS	0.87	92.4	94.2	9,396	8,831

5.3.6.3 Eight-Foot RDC HO GSFLs with CCTs $\leq 4,500$ K

Baseline Lamps

DOE selected baseline lamps as reference points from which to measure changes resulting from potential energy conservation standards. As discussed in section 5.2, a baseline lamp is typically the most common, least efficacious lamp sold in a given product class. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit.

DOE considered a number of criteria when determining the appropriate baseline. The 8-foot RDC HO lamps have traditionally been manufactured in both T8 and T12 diameters. DOE analyzed a T8 8-foot RDC HO lamp as a baseline (see section 5.3.2 for a discussion of why DOE did not analyze a T12 baseline).

For the 8-foot RDC HO product class, no commercially available lamp at the existing standard level exists. Therefore, DOE modeled a baseline lamp for this product class. As stated in section 5.3.2, DOE used the ANSI rated wattage of the most common, least efficacious commercially available lamp and back calculated the lumen output required to develop an efficacy at the existing standard level. DOE applied the ratio of mean lumen output to initial lumen output of the most common, least efficacious commercially available lamp to the calculated initial lumen output of the modeled baseline lamp to determine mean lumen output.

DOE assumed the modeled baseline lamp would have similar characteristics as the most common commercially available 8-foot RDC HO lamps. The most popular wattage associated with the 8-foot T8 RDC HO lamp type is 86 W. The typical performance characteristics of an 86 W T8 lamp include use of 700 series rare earth phosphor, CCT of 4,100 K, and a rated lifetime of 18,000 hours when paired with an IS ballast. A basic rare earth phosphor coating would likely be used to achieve the lower efficacy of the modeled baseline lamp. However because manufacturers may choose different phosphor coatings, DOE could not determine the exact CRI that would be utilized. Table 5.3.23 lists the characteristics of the modeled 86 W T8 8-foot RDC HO baseline lamp.

Table 5.3.23 Baseline Lamp for the 8-foot RDC HO Representative Product Class

Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	CRI	CCT
	W	W	lm/W	lm	lm	hr		K
T8	86	84.0	92.0	7,728	7,342	18,000	-	4,100

Efficacy Levels and More Efficacious Substitutes

In general terms, DOE based its ELs on the design options described below. Because utilizing higher efficiency phosphors is the most common method to achieve higher efficacies, DOE describes the phosphor technology associated with each EL:

EL 1: This level represents a 700 series full wattage (86 W) T8 lamp with basic coating, gas composition, and phosphor mix.

EL 2: This level requires the use of a basic 800 series rare earth phosphor and represents max tech, the most efficacious products available today.

Figure 5.3.5 illustrates the initial ELs on a plot with the representative lamps. A line at 92 lm/W denotes the existing energy conservation standard (the July 2012 standards). The square box identifies the baseline lamp. The plot also shows more efficacious substitutes DOE considered as replacement lamps. In this product class, all of the representative units shown on the plot are at the same wattage, but have a higher efficacy.

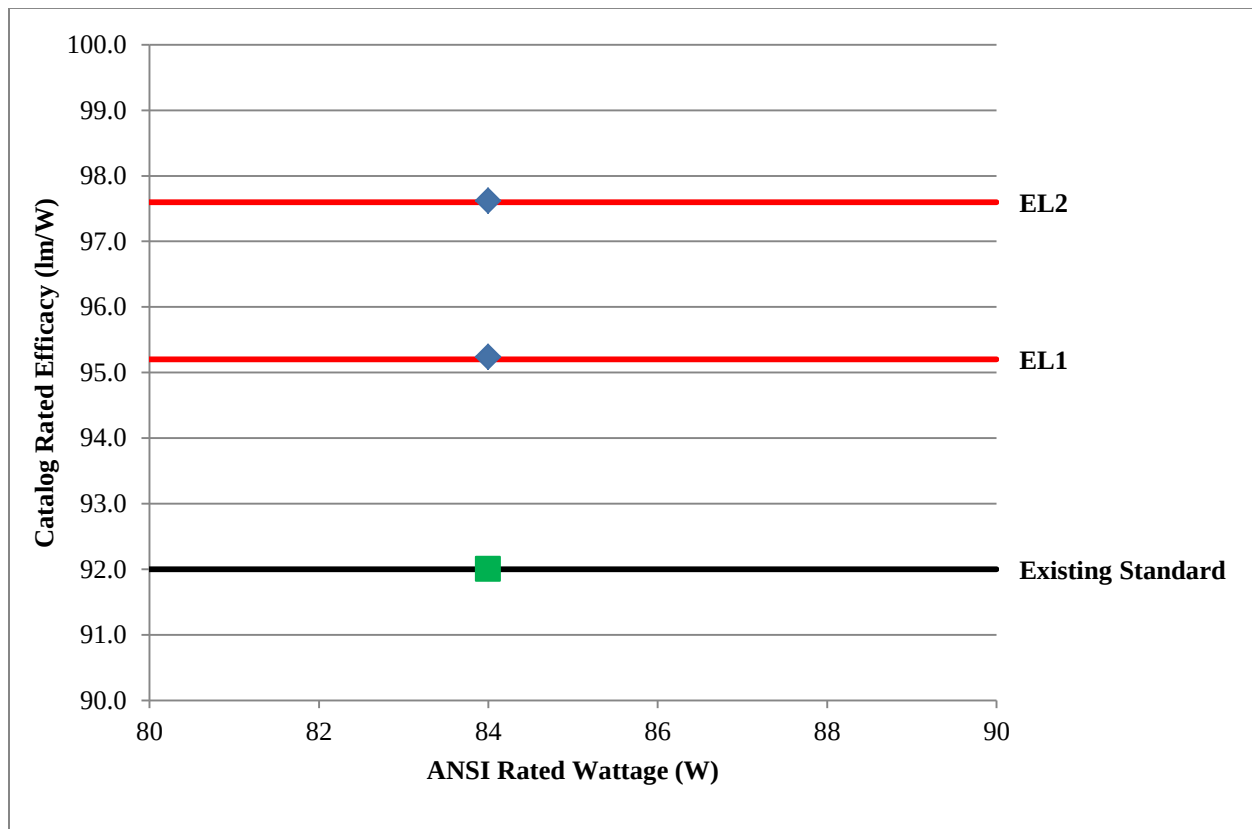


Figure 5.3.5 Efficacy Levels for 8-foot RDC HO GSFLs with CCTs $\leq$ 4,500 K

Table 5.3.24 provides detailed information on the 8-foot RDC HO representative lamps used in the engineering analysis and subsequent analyses.

Table 5.3.24 8-foot RDC HO Representative Lamps

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	CRI
		W	W	lm/W	lm	lm	hr	
Baseline	T8	86	84.0	92.0	7,728	7,342	18,000	-
1	T8	86	84.0	95.2	8,000	7,600	18,000	78
2	T8	86	84.0	97.6	8,200	7,800	18,000	85

As discussed above, DOE used commercially available lamps when possible and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) to determine each initial EL. However, to establish the minimum efficacy requirements for each EL, DOE also considered data submitted to DOE by manufacturers to demonstrate compliance with existing energy conservation standards. DOE determined if any adjustments were necessary to the initial ELs to account for compliance efficacies of representative units and/or equivalent lamps. DOE considered equivalent lamps to be manufacturer-identified cross references of the representative units or lamps deemed to have equivalent characteristics.

By examining publicly available compliance reports, DOE found that approximately 73 percent of available 8-foot RDC HO lamps analyzed had compliance information. Based on this information, DOE found that an adjustment to EL 1 was necessary. DOE adjusted EL 1 from 95.2 lm/W to 94.0 lm/W based on available compliance data for 700 series full wattage T8 lamps. DOE determined that the 800 series full wattage T8 representative unit and/or equivalent lamps complied with EL 2 and thus no adjustment was necessary. Figure 5.3.6 summarizes all available compliance information by lamp design (*i.e.*, 700 series and 800 series) and resulting ELs.

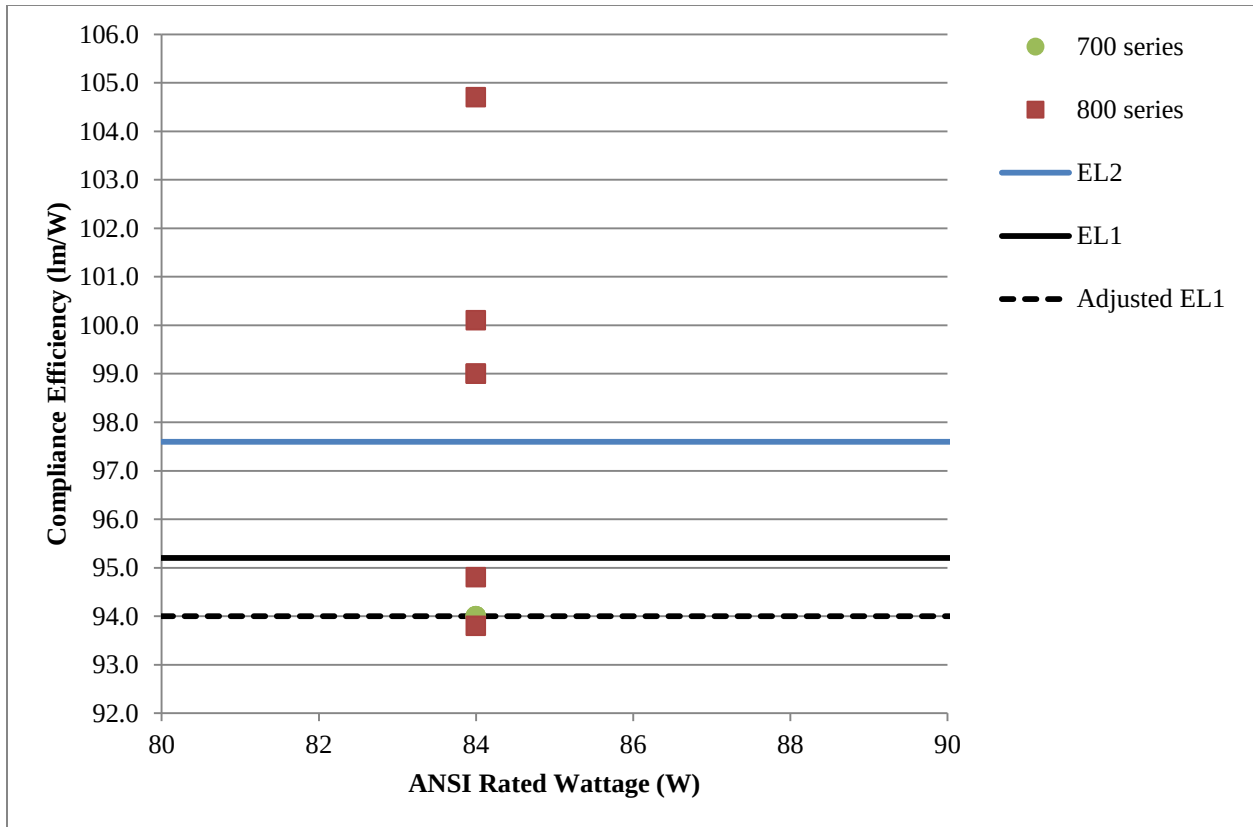


Figure 5.3.6 All Compliance Report Data for 8-foot RDC HO GSFLs with CCTs $\leq 4,500$ K

Table 5.3.25 summarizes the final efficacy requirement at EL 1 and EL 2.

Table 5.3.25 EL 1 and EL 2 for 8-foot RDC HO GSFLs with CCTs $\leq 4,500$ K

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	94.0
EL 2	97.6

Engineering Summary

The first set of results present the lamp replacement scenario for the 8-foot RDC HO representative product class. In this scenario, energy savings are achieved through the use of higher efficacy, reduced wattage lamps. However, for this product class, DOE identified no commercially available reduced wattage 8-foot RDC HO lamps. Therefore, the lamp replacement scenario only analyzes more efficient full wattage 8-foot RDC HO lamps as replacements. Table 5.3.26 presents the engineering analysis results for two-lamp 8-foot RDC HO systems operating in the commercial and industrial sectors.

Table 5.3.26 Lamp Replacement Engineering Analysis for a Two-Lamp Instant Start 86 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	86	84	92.0	7,728	7,342	18,000	2	IS	0.81	148.4	91.7	12,519	11,893
EL 1	T8	86	84	95.2	8,000	7,600	18,000	2	IS	0.81	148.4	91.7	12,960	12,312
EL 2	T8	86	84	97.6	8,200	7,800	18,000	2	IS	0.81	148.4	91.7	13,284	12,636

The next set of engineering results present the lamp-and-ballast replacement scenario for the 8-foot RDC HO representative product class. For this scenario, as stated in section 5.3.5, the ballast with the lowest possible BF was selected that still maintained system mean lumen output within 10 percent of the baseline system. For this product class, no low BF ballast was identified, thus the same ballast was utilized at the higher efficacy levels. Table 5.3.27 presents the engineering analysis results for the replacement lamp-and-ballast combination for two-lamp 8-foot RDC HO IS systems in the commercial and industrial sectors.

Table 5.3.27 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Instant Start 86 W T8, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T8	86	84	92.0	7,728	7,342	18,000	2	IS	0.81	148.4	91.7	12,519	11,893
EL 1	T8	86	84	95.2	8,000	7,600	18,000	2	IS	0.81	148.4	91.7	12,960	12,312
EL 2	T8	86	84	97.6	8,200	7,800	18,000	2	IS	0.81	148.4	91.7	13,284	12,636

5.3.6.4 Four-Foot T5 MiniBP SO GSFLs with CCTs $\leq 4,500$ K

Baseline Lamps

DOE selected baseline lamps as reference points from which to measure changes resulting from potential energy conservation standards. As discussed in section 5.2, a baseline lamp is typically the most common, least efficacious lamp sold in a given product class. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit.

For the T5 MiniBP SO product class, no commercially available lamp at the existing standard level exists. Therefore, DOE modeled a baseline lamp for this product class. As stated in section 5.3.2, DOE used the ANSI rated wattage of the most common, least efficacious commercially available lamp and back calculated the lumen output required to develop an efficacy at the existing standard level. DOE applied the ratio of mean lumen output to initial lumen output of the most common, least efficacious commercially available lamp to the calculated initial lumen output of the modeled baseline lamp to determine mean lumen output. DOE then calculated the expected increase in lumen output for lamp operation at 35 °C by increasing the calculated initial and mean lumen output at 25 °C by 10 percent.

DOE assumed the modeled baseline lamp would have similar characteristics as the most common commercially available 4-foot T5 MiniBP SO lamps. The most popular wattage associated with the 4-foot T5 MiniBP SO product class is 28 W. The typical performance characteristics of a 28 W 4-foot T5 MiniBP SO baseline lamp include use of 800 series rare earth phosphors, however because the modeled lamp is substantially less efficient than commercially available lamps, the rare earth phosphor required may not be 800 series. A basic rare earth phosphor coating would likely be used to achieve the lower efficacy of the modeled baseline lamp. However because manufacturers may choose different phosphor coatings, DOE could not determine the exact CRI that would be utilized. Additional performance characteristics for this lamp type are a CCT of 4,100 K and a rated lifetime of 30,000 hours when paired with a PS ballast. Table 5.3.28 lists the characteristics of the 28 W 4-foot T5 MiniBP SO baseline lamp.

Table 5.3.28 Baseline Lamp for the 4-foot T5 MiniBP Standard Output Representative Product Class

Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 25 °C (at 35 °C)	Initial Lamp Light Output at 25 °C (at 35 °C)	Mean Lamp Light Output at 25 °C (at 35 °C)	Rated Life	CRI	CCT
	W	W	lm/W	lm	lm	hr		K
T5	28	27.8	86.0 (94.6)	2,391 (2,630)	2,223 (2,446)	30,000	-	4,100

Efficacy Levels and More Efficacious Substitutes

The following discussion identifies the steps and technologies associated with the EL DOE considered for the 4-foot T5 MiniBP SO representative product class. DOE is aware that many T5 SO lamps are operated at 35 °C and all manufacturers report performance at 35 °C in their catalogs. Therefore, DOE selected more efficacious replacements and developed initial ELs for T5 SO lamps based on 35 °C catalog data. However, the DOE test procedure for T5 lamps requires the lamps to be tested at 25 °C. Because the test procedure is used to determine compliance with DOE energy conservation standards, DOE adjusted the ELs by applying a 10 percent reduction to reflect the efficacy at 25 °C. When operated at 25 °C, the lumen output of T5 lamps is approximately 10 percent lower than the lumen output of such lamps when operated at 35 °C. DOE also utilized certain manufacturers' catalog information if performance characteristics were provided for lamp operation at 25 °C.

In general terms, DOE based its ELs on the design options described below. Because utilizing higher efficiency phosphors is the most common method to achieve higher efficacies, DOE describes the phosphor technology associated with each EL:

EL 1: This level represents an 800 series full wattage (28 W) lamp with basic coating, gas composition, and phosphor mix.

EL 2: This level represents higher efficacy improved 800 series phosphor 4-foot T5 MiniBP SO lamps in which the phosphor mix and/or coating is enhanced. Full wattage 28 W lamps meet this level. The full wattage 28 W lamps that meet this level have a rated efficacy of 109.7 lm/W at 35 °C and 98.2 lm/W at 25 °C operation. For reduced wattage lamps, a reduced wattage 26 W 4-foot T5 MiniBP SO lamp and a reduced wattage 25 W lamp also meet this level. The 26 W reduced wattage lamps that meet this level have a rated efficacy of 111.5 lm/W at 35 °C and 100.0 lm/W at 25 °C operation. The 25 W reduced wattage lamps that meet this level have a rated efficacy of 116.0 lm/W at 35 °C and 104.0 lm/W at 25 °C operation. This level represents max tech, the most efficacious products available today.

DOE developed initial ELs based on catalog values of more efficacious lamps that DOE selected to analyze as representative units. The existing energy conservation standard (the July 2012 standards) is 86 lm/W (at 25 °C). Figure 5.3.7 illustrates the initial ELs for this rulemaking on a plot of the efficacies of the representative lamps at 25 °C. The square box identifies the baseline lamp. The plot also shows the more efficacious substitutes DOE considered as replacement lamps. Some of the representative units shown on the plot are at the same wattage as the baseline, but have a higher efficacy; others have a combination of lower wattage and higher efficacy.

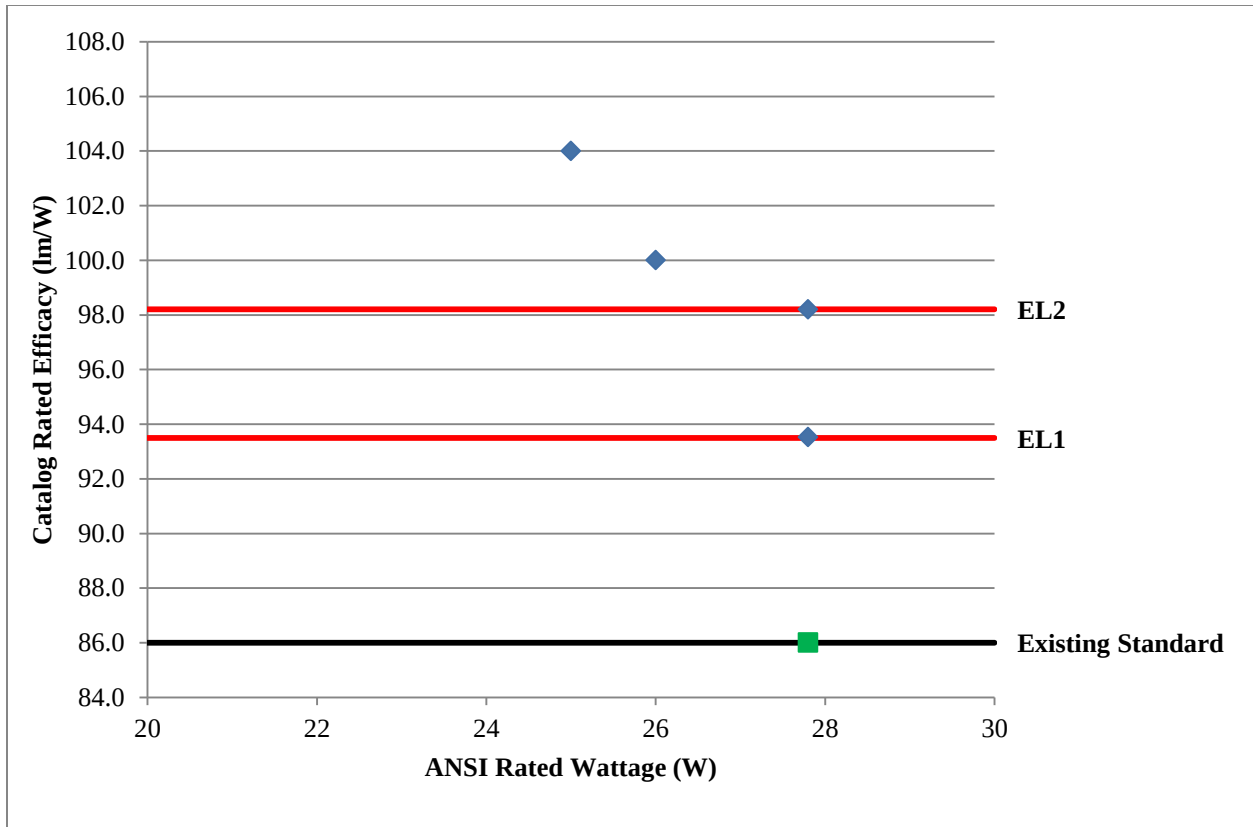


Figure 5.3.7 Efficacy Levels for 4-foot T5 MiniBP SO GSFLs with CCTs $\leq 4,500$ K, at 25 °C

Table 5.3.29 provides detailed information on the 4-foot T5 MiniBP SO representative lamps used in the engineering analysis and subsequent analyses.

Table 5.3.29 4-foot T5 MiniBP SO Representative Lamps

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 25 °C (at 35 °C)	Initial Lamp Light Output at 25 °C (at 35 °C)	Mean Lamp Light Output at 25 °C (at 35 °C)	Rated Life	CRI
		W	W	lm/W	lm	lm	hr	
Baseline	T5	28	27.8	86.0 (94.6)	2,391 (2,630)	2,223 (2,446)	30,000	-
1	T5	28	27.8	93.5 (104.3)	2,600 (2,900)	2,418 (2,697)	30,000	85
2	T5	28	27.8	98.2 (109.7)	2,730 (3,050)	2,594 (2,898)	30,000	85
2	T5	26	26.0	100.0 (111.5)	2,600 (2,900)	2,470 (2,755)	30,000	85
2	T5	25	25.0	104.0 (116.0)	2,600 (2,900)	2,475 (2,750)	35,000	85

As discussed above, DOE used commercially available lamps when possible and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) at 35 °C to determine the initial ELs. DOE then adjusted the ELs to take into account the efficacy at 25 °C. To establish the minimum efficacy requirements for each EL, DOE also considered data submitted to DOE by manufacturers to demonstrate compliance with existing energy conservation standards. DOE determined if any adjustments were necessary to the initial ELs to account for compliance efficacies of representative units and/or equivalent lamps. DOE considered equivalent lamps to be manufacturer-identified cross references of the representative units or lamps deemed to have equivalent characteristics.

By examining publicly available compliance reports, DOE found that approximately 75 percent of available 4-foot T5 MiniBP SO lamps had compliance information. Using this information, DOE was able to confirm that for the 800 series full wattage lamps, all representative units and/or equivalent lamps complied with EL 1. Thus, based on compliance information, DOE determined that no adjustment to EL 1 was necessary. For EL 2 representing improved 800 series full wattage T8 lamps, DOE determined an adjustment was necessary. DOE adjusted EL 2 from 98.2 lm/W to 97.1 lm/W based on available certification data for improved 800 series full wattage T8 lamps. Figure 5.3.8 summarizes all available compliance information by lamp design (*i.e.*, basic 800 series, improved 800 series, reduced wattage, and other^o) and the resulting ELs.

^o Lamps labeled as “other” designate lamp designs that are not representative of the most common characteristics identified.

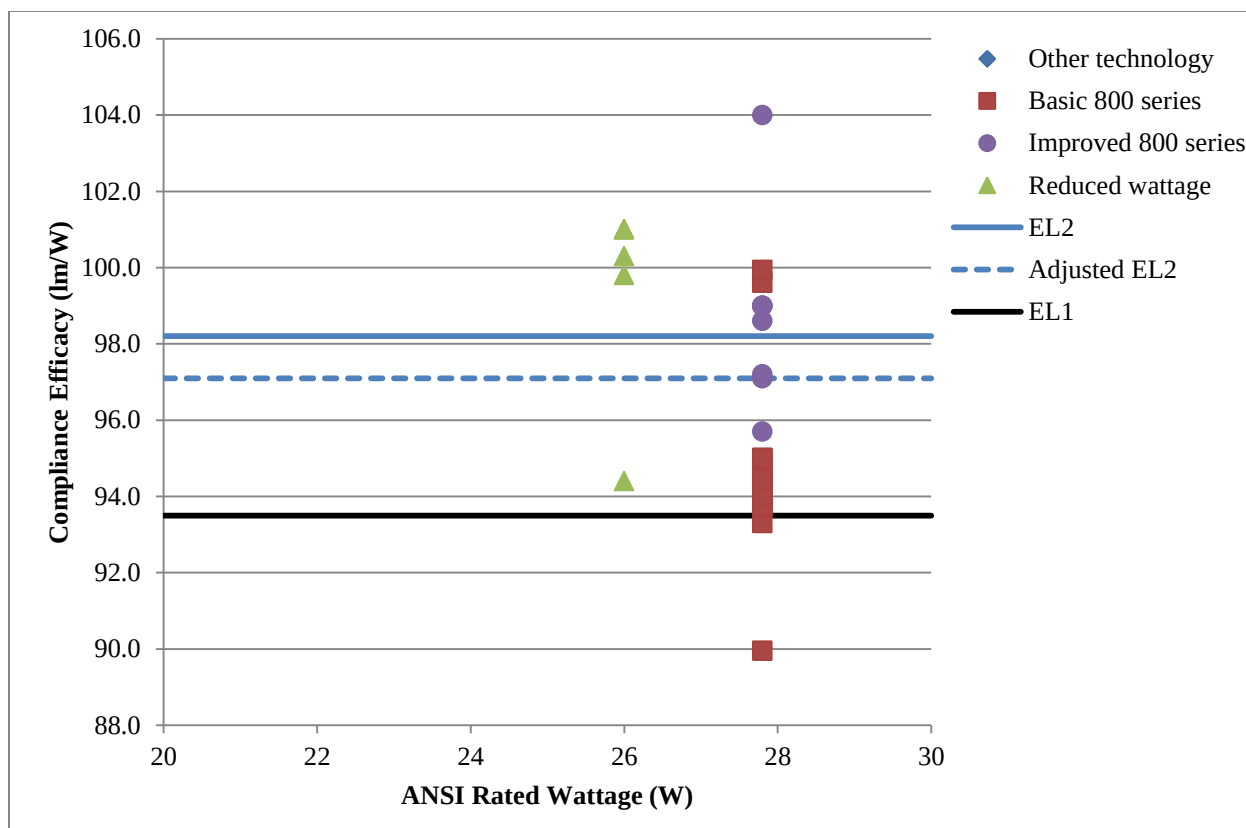


Figure 5.3.8 All Compliance Report Data for 4-foot T5 MiniBP SO GSFLs with CCTs $\leq$ 4,500 K, at 25 °C

Table 5.3.30 summarizes the final efficacy requirements at EL 1 and EL 2.

Table 5.3.30 EL 1 and EL 2 for 4-foot T5 MiniBP SO GSFLs with CCTs $\leq$ 4,500 K

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	93.5
EL 2	97.1

Engineering Summary

The first set of results present the lamp replacement scenario for the 4-foot T5 MiniBP SO representative product class. In this scenario, energy savings are achieved through the use of higher efficacy, reduced wattage lamps. Higher efficacy, full wattage lamps are also analyzed, however, no energy savings are achieved for these replacements. As stated in section 5.3.4, replacement lamp options were selected so that the system mean lumen output was within 10 percent of the baseline when possible. Table 5.3.31 presents the engineering analysis results for two-lamp 4-foot T5 MiniBP SO PS systems operating in the commercial and industrial sectors.

Table 5.3.31 Lamp Replacement Engineering Analysis for a Two-Lamp Programmed Start 28 W T5, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T5	28	27.8	94.6	2,630	2,446	30,000	2	PS	1.00	60.4	92.1	5,260	4,892
EL 1	T5	28	27.8	104.3	2,900	2,697	30,000	2	PS	1.00	60.4	92.1	5,800	5,394
EL 2	T5	28	27.8	109.7	3,050	2,898	30,000	2	PS	1.00	60.4	92.1	6,100	5,796
EL 2	T5	26	26.0	111.5	2,900	2,755	30,000	2	PS	1.00	56.6	91.9	5,800	5,510
EL 2	T5	25	25.0	116.0	2,900	2,750	35,000	2	PS	1.00	54.5	91.8	5,800	5,500

The next set of engineering results present the lamp-and-ballast replacement scenario for the 4-foot T5 MiniBP SO representative product class. For this scenario, as stated in section 5.3.5, the ballast with the lowest possible BF was selected that still maintained system mean lumen output within 10 percent of the baseline system when possible. Table 5.3.32 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 4-foot T5 MiniBP SO PS systems in the commercial and industrial sectors.

Table 5.3.32 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Programmed Start 28 W T5, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T5	28	27.8	94.6	2,630	2,446	30,000	2	PS	1.00	60.4	92.1	5,260	4,892
EL 1	T5	28	27.8	104.3	2,900	2,697	30,000	2	PS	0.85	53.0	89.2	4,930	4,585
EL 2	T5	28	27.8	109.7	3,050	2,898	30,000	2	PS	0.85	53.0	89.2	5,185	4,927
EL 2	T5	26	26.0	111.5	2,900	2,755	30,000	2	PS	0.85	49.7	88.9	4,930	4,684
EL 2	T5	25	25.0	116.0	2,900	2,750	35,000	2	PS	0.85	47.9	88.8	4,930	4,675

5.3.6.5 Four-Foot T5 MiniBP HO GSFLs with CCTs $\leq 4,500$ K

Baseline Lamps

DOE selected baseline lamps as reference points from which to measure changes resulting from potential energy conservation standards. As discussed in section 5.2, a baseline lamp is typically the most common, least efficacious lamp sold in a given product class. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit.

For the T5 MiniBP HO product class, no commercially available lamp at the existing standard level exists. Therefore, DOE modeled a baseline lamp for this product class. As stated in section 5.3.2, DOE used the ANSI rated wattage of the most common, least efficacious commercially available lamp and back calculated the lumen output required to develop an efficacy at the existing standard level. DOE applied the ratio of mean lumen output to initial lumen output of the most common, least efficacious commercially available lamp to the calculated initial lumen output of the modeled baseline lamp to determine mean lumen output. DOE then calculated the expected increase in lumen output for lamp operation at 35 °C by increasing the calculated initial and mean lumen output at 25 °C by 10 percent.

DOE assumed the modeled baseline lamp would have similar characteristics as the most common commercially available 4-foot T5 MiniBP HO lamps. The most popular wattage associated with the 4-foot T5 MiniBP HO product class is 54 W. Typical performance characteristics for a 54 W 4-foot T5 MiniBP HO include use of 800 series rare earth phosphors, however because the modeled lamp is substantially less efficient than commercially available lamps, the rare earth phosphor required may not be 800 series. A basic rare earth phosphor coating would likely be used to achieve the lower efficacy of the modeled baseline lamp. However because manufacturers may choose different phosphor coatings, DOE could not determine the exact CRI that would be utilized. Additional performance characteristics for this lamp type are a CCT of 4,100 K and a rated lifetime of 25,000 hours when paired with a PS ballast. Table 5.3.33 lists the characteristics of the 54 W 4-foot T5 MiniBP HO baseline lamp.

Table 5.3.33 Baseline Lamp for the 4-foot T5 MiniBP High Output Representative Product Class

Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 25 °C (at 35 °C)	Initial Lamp Light Output at 25 °C (at 35 °C)	Mean Lamp Light Output at 25 °C (at 35 °C)	Rated Life	CRI	CCT
	W	W	lm/W	lm	lm	hr		K
T5	54	53.8	76.0 (83.6)	4,089 (4,498)	3,884 (4,273)	25,000	-	4,100

Efficacy Levels and More Efficacious Substitutes

The following discussion identifies the steps and technologies associated with the EL DOE considered for the 4-foot T5 MiniBP HO representative product class. DOE is aware that many T5 MiniBP HO lamps are operated at 35 °C and all manufacturers report performance at 35 °C in their catalogs. Therefore, DOE selected more efficacious replacements and developed an initial EL for T5 MiniBP HO lamps based on 35 °C catalog data. However, The DOE test procedure for T5 lamps requires the lamps to be tested at 25 °C. Because the test procedure is used to determine compliance with DOE energy conservation standards, DOE adjusted the EL by applying a 10 percent reduction to reflect the efficacy at 25 °C. When operated at 25 °C, the lumen output of T5 lamps is approximately 10 percent lower than the lumen output of such lamps when operated at 35 °C. DOE also utilized certain manufacturers' catalog information if performance characteristics were provided for lamp operation at 25 °C.

In general terms, DOE based EL 1 on the design options described below. Because utilizing higher efficiency phosphors is the most common method to achieve higher efficacies, DOE describes the phosphor technology associated with the EL:

EL 1: This level is represented by an 800 series phosphor full wattage T5 lamp with basic coating, gas composition, and phosphor mix. Several reduced wattage lamps also meet this level. Specifically, a reduced wattage 49 W lamp and a reduced wattage 47 W lamp meet this level. The 49 W reduced wattage lamps that meet this level have a rated efficacy of 102.0 lm/W at 35 °C and 90.8 lm/W at 25 °C operation. The 47 W reduced wattage lamps that meet this level have a rated efficacy of 102.1 lm/W at 35 °C and 91.9 lm/W at 25 °C operation. This level represents max tech, the most efficacious products available today.

DOE developed an initial EL based on catalog values of more efficacious lamps that DOE selected to analyze as representative units. The existing energy conservation standard (the July 2012 standards) is 76 lm/W (at 25 °C). Figure 5.3.9 illustrates the initial EL for this rulemaking on a plot of the efficacies of the representative lamps at 25 °C. The square box identifies the baseline lamp. The plot also shows the more efficacious substitutes DOE considered as replacement lamps. Some of the representative units shown on the plot are at the same wattage as the baseline, but have a higher efficacy; others have a combination of lower wattage and higher efficacy.

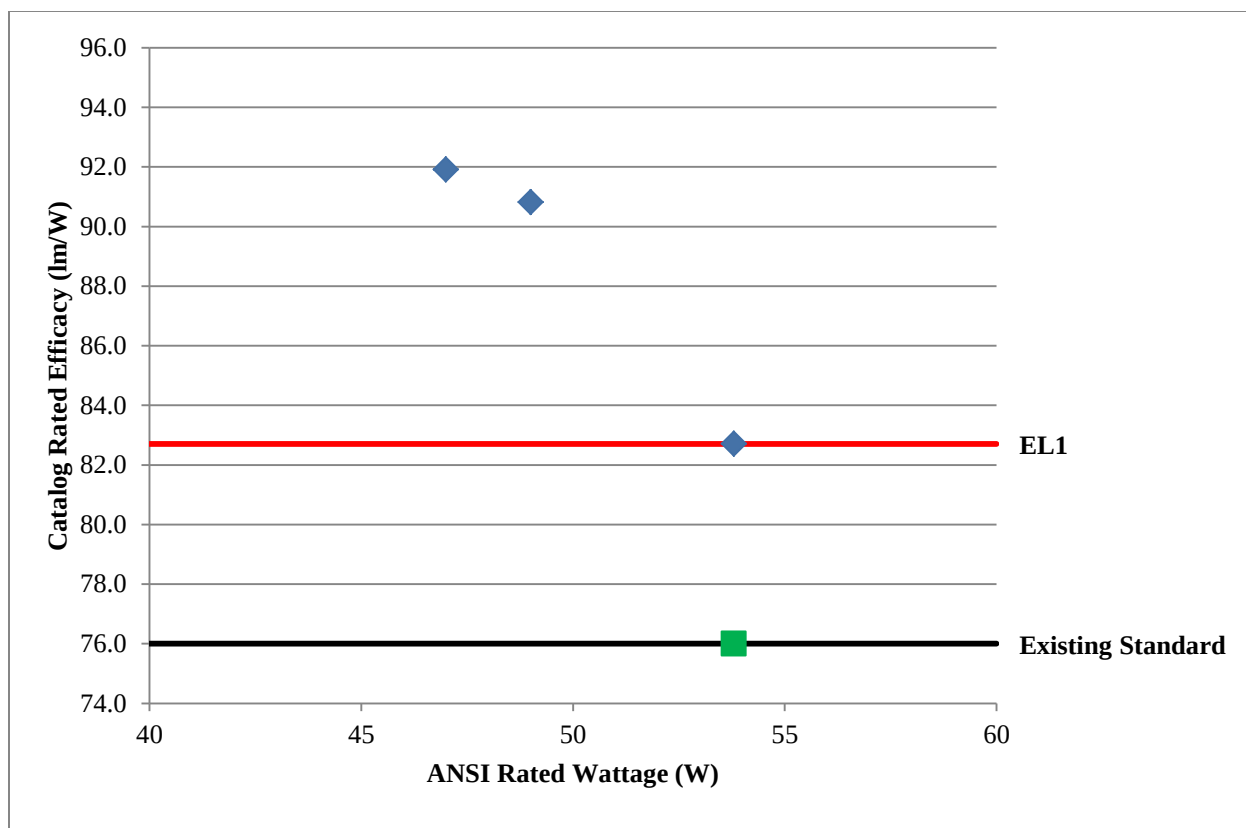


Figure 5.3.9 Efficacy Level for 4-foot T5 MiniBP HO GSFLs with CCTs ≤ 4,500 K, at 25 °C

Table 5.3.34 provides detailed information on the 4-foot T5 MiniBP HO representative lamps used in the engineering analysis and subsequent analyses.

Table 5.3.34 4-foot T5 MiniBP HO Representative Lamps

EL	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 25 °C (at 35 °C)	Initial Lamp Light Output at 25 °C (at 35 °C)	Mean Lamp Light Output at 25 °C (at 35 °C)	Rated Life	CRI
		W	W	lm/W	lm	lm	hr	
Baseline	T5	54	53.8	76.0 (83.6)	4,089 (4,498)	3,884 (4,273)	25,000	-
1	T5	54	53.8	82.7 (92.9)	4,450 (5,000)	4,275 (4,750)	25,000	85
1	T5	49	49.0	90.8 (102.0)	4,450 (5,000)	4,140 (4,600)	35,000	85
1	T5	47	47.0	91.9 (102.1)	4,320 (4,800)	3,969 (4,410)	30,000	84

As discussed above, DOE used commercially available lamps, when possible, and their associated rated efficacies (catalog initial lumen output divided by the ANSI rated wattage) at 35 °C to determine the initial EL. DOE then adjusted the EL to take into account the efficacy at 25

°C. To establish the minimum efficacy requirements for each EL, DOE also considered data submitted to DOE by manufacturers to demonstrate compliance with existing energy conservation standards. DOE determined if any adjustments were necessary to the initial EL to account for compliance efficacies of representative units and/or equivalent lamps. DOE considered equivalent lamps to be manufacturer-identified cross references of the representative units or lamps deemed to have equivalent characteristics.

By examining publicly available compliance reports, DOE found that approximately 75 percent of available 4-foot T5 MiniBP HO lamps had compliance information. Using this information, DOE was able to confirm that the full wattage and reduced wattage representative units and/or equivalent lamps complied with EL 1. Thus, based on compliance information, DOE determined that no adjustment to EL 1 was necessary. Figure 5.3.10 summarizes all available compliance information by lamp design (*i.e.*, basic 800 series, reduced wattage, and other^p) and the resulting EL.

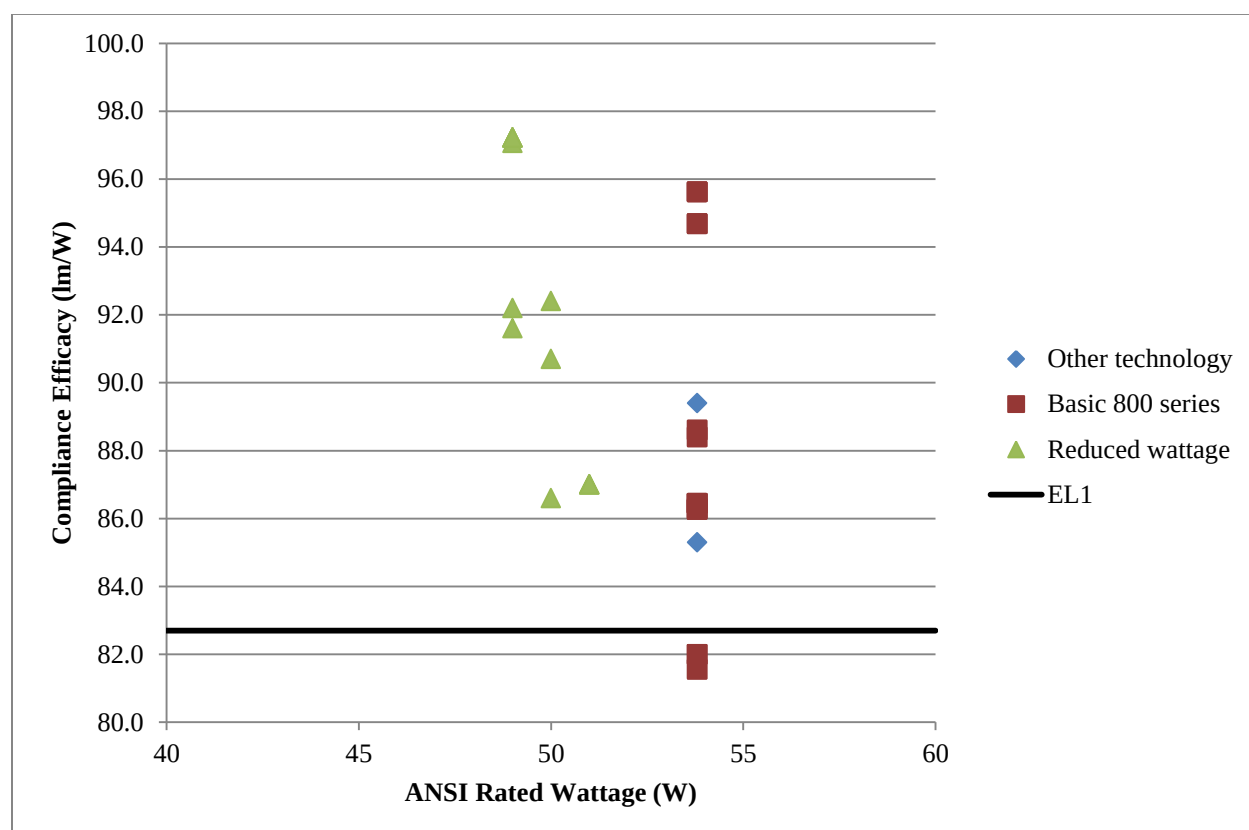


Figure 5.3.10 All Compliance Report Data for 4-foot T5 MiniBP HO GSFLs with CCTs $\leq$ 4,500 K, at 25 °C

^p Lamps labeled as “other” designate lamp designs that are not representative of the most common characteristics identified.

Table 5.3.35 summarizes the final efficacy requirement at EL 1.

Table 5.3.35 EL 1 for 4-foot T5 MiniBP HO GSFLs with CCTs $\leq$ 4,500 K

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	82.7 lm/W

Engineering Summary

The first set of results present the lamp replacement scenario for the 4-foot T5 MiniBP HO representative product class. In this scenario, energy savings are achieved through the use of higher efficacy, reduced wattage lamps. Higher efficacy, full wattage lamps are also analyzed, however, no energy savings are achieved for these replacements. As stated in section 5.3.4, replacement lamp options were selected so that the system mean lumen output was within 10 percent of the baseline when possible. Table 5.3.36 presents the engineering analysis results for two-lamp 4-foot T5 MiniBP HO PS systems operating in the commercial and industrial sectors.

Table 5.3.36 Lamp Replacement Engineering Analysis for a Two-Lamp Programmed Start 54 W T5, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T5	54	53.8	83.6	4,498	4,273	25,000	2	PS	1.00	116.5	92.4	8,995	8,546
EL 1	T5	54	53.8	92.9	5,000	4,750	25,000	2	PS	1.00	116.5	92.4	10,000	9,500
EL 1	T5	49	49.0	102.0	5,000	4,600	35,000	2	PS	1.00	106.4	92.1	10,000	9,200
EL 1	T5	47	47.0	102.1	4,800	4,410	30,000	2	PS	1.00	102.2	92.0	9,600	8,820

The next set of engineering results present the lamp-and-ballast replacement scenario for the 4-foot T5 MiniBP HO representative product class. For this scenario, as stated in section 5.3.5, the ballast with the lowest possible BF was selected that still maintained system mean lumen output within 10 percent of the baseline system when possible. For this product class, DOE could not consider installing a lamp on a lower BF ballast to save energy, as ballasts with a BF lower than 1.0 are not commercially available. Table 5.3.37 presents the engineering analysis results for the replacement lamp-and-ballast combinations for two-lamp 4-foot T5 MiniBP HO PS systems in the commercial and industrial sectors.

Table 5.3.37 Lamp-and-Ballast Replacement Engineering Analysis for a Two-Lamp Programmed Start 54 W T5, 4,100 K System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		W	W	lm/W	lm	lm	hr				W		lm	lm
Baseline	T5	54	53.8	83.6	4,498	4,273	25,000	2	PS	1.00	116.5	92.4	8,995	8,546
EL 1	T5	54	53.8	92.9	5,000	4,750	25,000	2	PS	1.00	116.5	92.4	10,000	9,500
EL 1	T5	49	49.0	102.0	5,000	4,600	35,000	2	PS	1.00	106.4	92.1	10,000	9,200
EL 1	T5	47	47.0	102.1	4,800	4,410	30,000	2	PS	1.00	102.2	92.0	9,600	8,820

5.3.7 Scaling to Product Classes Not Analyzed

DOE identified and selected certain product classes as representative product classes on which to concentrate its analytical effort. DOE chose these representative product classes primarily due to their high market volumes. The following sections discuss how DOE scaled ELs from the analyzed product classes to those product classes not directly analyzed.

5.3.7.1 2-foot U-Shaped GSFLs with CCTs $\leq 4,500$ K

DOE utilized the 4-foot MBP linear fluorescent products to scale to the 2-foot U-shaped products, as both products use the same fluorescent technology, span the same range of wattages, and, without its bent curve, the 2-foot U-shaped would be approximately the same length as the 4-foot MBP linear lamp. DOE analyzed certification data for the 2-foot U-shaped scaling based on feedback received from manufacturers indicating that confounding factors exist that are not reflected in catalog data. DOE confirmed that certification data indicated a greater scaling factor was necessary compared to catalog data. Thus, DOE compared the certification data of commercially available 2-foot U-shaped lamps with CCTs less than or equal to 4,500 K and the equivalent 4-foot MBP version (*i.e.*, the only difference between the two lamp types is shape). Based on this comparison DOE determined an average efficacy reduction for the 2-foot U-shaped lamps from the 4-foot MBP lamps was appropriate. Therefore, DOE reduced EL 1 and EL 2 by 6 percent to 84.6 lm/W and 86.9 lm/W, respectively. DOE confirmed that the scaled standard levels resulted in a similar technology impact at each EL (see 5.3.6.1 for these technology impacts). DOE also confirmed that the scaling factor did not result in backsliding from the current standards. Table 5.3.38 shows the efficacy levels for these lamps.

Table 5.3.38 Efficacy Requirements for 2-foot U-Shaped Lamps with CCTs Less Than or Equal To 4,500 K

EL	Efficacy Requirement (lm/W)		Reduction
	4-foot MBP	2-foot U-Shaped	
1	90.0	84.6	6%
2	92.4	86.9	6%

5.3.7.2 Lamps with CCTs Above 4,500 K

As discussed in 5.3.1, DOE is not analyzing GSFLs with CCTs above 4,500 K. The efficacy of higher CCT lamps is lower due to the quality of the blue light emitted. (See chapter 3 of this TSD for further information.) DOE examined the differences in efficacies between lower and higher CCT lamps in each product class based on performance data provided in manufacturer catalogs. DOE found variation in the percent reduction in efficacy associated with increased CCT among product classes and therefore chose to develop a separate scaling factor for each product class to account for the difference in efficacy between lamps with a CCT less than or equal to 4,500 K and greater than 4,500 K.

DOE identified pairs of lamps in which the only difference between the lamps was the CCT. DOE compared commercially available lamps at 4,100 K and 5,000 K, and 4,100 K and 6,500 K to determine differences in efficacy. DOE then calculated the average difference in

efficacy of all lamp pairs within a product class to determine the percent reduction in efficacy from the less than or equal to 4,500 K representative product classes. DOE is proposing to maintain a 2 percent scaling factor for the 4-foot MBP product class in order to ensure that any proposed level does not backslide from the current minimum standard. Based on its assessment, DOE determined a 3 percent scaling factor for the 2-foot U-shaped product class, 5 percent for the 8-foot SP slimline product class, 2 percent for the 8-foot RDC HO product class, 6 percent for the T5 SO product class, and 5 percent for the T5 HO product class were appropriate. For the 2-ft U-shaped product class with CCT greater than 4,500 K, DOE applied the 3 percent reduction to the scaled ELs for the 2-ft U-shaped product class.

DOE verified the scaling factors developed against certification data. DOE also confirmed that the scaled standard levels resulted in similar technology impacts at each EL. Table 5.3.39 shows the efficacy levels for these lamps.

Table 5.3.39 Efficacy Requirements for Product Classes with CCTs Greater Than 4,500 K

Product Class	EL	Efficacy Requirement <i>lm/W</i>		Reduction
		≤ 4,500 K	> 4,500 K	
4-foot MBP	1	90.0	88.2	2%
	2	92.4	90.6	2%
8-foot SP slimline	1	98.2	93.3	5%
	2	99.0	94.1	5%
8-foot RDC HO	1	94.0	92.1	2%
	2	97.6	95.6	2%
4-foot T5 MiniBP SO	1	93.5	87.9	6%
	2	97.1	91.3	6%
4-foot T5 MiniBP HO	1	82.7	78.6	5%
2-ft U-shaped	1	84.6	82.1	3%
	2	86.9	84.3	3%

5.3.8 Summary of All Efficacy Levels for Covered GSFLs

Table 5.3.40 shows a summary of ELs for all GSFLs covered by this rulemaking. “N/A” is shown where no ELs exist. Representative product classes are indicated by gray shading.

Table 5.3.40 Summary of All Efficacy Levels for Covered GSFLs

CCT	Lamp Type	Efficacy Level	
		1	2
≤ 4,500 K	4-foot medium bipin	90.0	92.4
	2-foot U-shaped	84.6	86.9
	8-foot single pin slimline	98.2	99.0
	8-foot recessed double contact HO	94.0	97.6
	4-foot T5 miniature bipin SO	93.5	97.1
	4-foot T5 miniature bipin HO	82.7	N/A
> 4,500 K	4-foot medium bipin	88.2	90.6
	2-foot U-shaped	82.1	84.3
	8-foot single pin slimline	93.3	94.1
	8-foot recessed double contact HO	92.1	95.6
	4-foot T5 miniature bipin SO	87.9	91.3
	4-foot T5 miniature bipin HO	78.6	N/A

5.4 INCANDESCENT REFLECTOR LAMPS

5.4.1 Representative Product Classes

As discussed in the market and technology assessment (chapter 3 of this TSD), DOE is considering eight separate IRL product classes based on three class-setting factors: spectrum, diameter, and input voltage. Of these product classes, DOE chose the standard spectrum, voltage less than 125 V, diameter greater than 2.5 inches product class as representative due to the prevalence of these lamps in the market. Information from manufacturer interviews and a review of product catalogs revealed that standard spectrum lamps represent the vast majority of IRLs. DOE research and manufacturer feedback also indicated that IRLs with diameters greater than 2.5 inches are more common than those with smaller diameters; specifically, the majority of consumers purchase parabolic aluminized reflector (PAR)30 or PAR38 IRLs. Additionally, DOE found that most consumers purchase IRLs rated at 120 V.

Table 5.4.1 lists the eight product classes and identifies the representative product class that DOE is considering in this NOPR analysis.

Table 5.4.1 Product Classes for Incandescent Reflector Lamps

Lamp Type	Diameter	Voltage
Standard spectrum	> 2.5 inches	≥ 125
		< 125 (representative)
	≤ 2.5 inches	≥ 125
		< 125
Modified spectrum	> 2.5 inches	≥ 125
		< 125
	≤ 2.5 inches	≥ 125
		< 125

5.4.2 Baseline Lamp

For each representative product class, DOE selects a baseline lamp that is typically the most common, least efficacious lamp that just meets standards. To identify a baseline lamp, DOE reviews product offerings in catalogs, shipment information, and manufacturer feedback obtained during interviews.

DOE selected a baseline lamp as a reference point from which DOE measured changes resulting from potential energy conservation standards. To determine energy savings and changes in price, DOE compared representative lamps at each higher efficacy level with the baseline unit. DOE considered a number of criteria when selecting which commercially available lamp would serve as a baseline. First, DOE selected a PAR38 lamp as the baseline based on the diameter's high shipment volume. Then, DOE identified typical characteristics for these types of

lamps (i.e., wattage, lifetime, lumen package, and rated efficacy^q). Among all PAR38 lamps with the most common characteristics, DOE selected one lamp that just met existing standards as the baseline: a halogen lamp with a lifetime of 1,500 hours that utilizes a higher efficiency inert fill gas and a higher efficiency reflector coating.

A summary of the IRL baseline lamp selected for the representative product class is shown in Table 5.4.2.

Table 5.4.2 IRL Baseline Lamp

Representative Product Class	Baseline Lamp					
	Lamp Type	Descriptor	Wattage	Efficacy	Initial Light Output	Lifetime
			<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>hr</i>
Standard Spectrum, Voltage < 125 V, Diameter > 2.5 Inches	PAR38	Improved Halogen	60	17.8	1,070	1,500

5.4.3 More Efficacious Substitutes

After choosing a baseline lamp for each representative product class, DOE identifies IRLs that are commercially available that can serve as more efficacious substitutes. DOE only considered more efficacious substitutes with the same reflector shape as the baseline lamp (PAR38). When identifying substitutes, DOE used catalog efficacy values to identify higher efficacy replacement lamps. DOE selected more efficacious replacement lamps that both save energy (with wattages less than the baseline lamp wattage of 60 W) and maintain comparable light output when possible. Similar to GSFLs, consumers take lumen package into consideration when purchasing IRLs. Therefore, DOE analyzed commercially available, reduced wattage lamps that maintain light output within 10 percent of the baseline. DOE also only considered more efficacious substitutes with lifetimes equal to or greater than the baseline lifetime of 1,500 hours. DOE also ensured that lamps selected for analysis were commercially available in the United States.

In reviewing published catalog data, DOE observed that two higher efficacy, reduced wattage lamps that meet these criteria, referred to in this NOPR analysis as a halogen infrared reflector (HIR) lamp and an improved HIR lamp, can serve as substitutes for the baseline lamp. The reduced wattage designs utilize HIR technology, which refers to glass coatings that reflect infrared light. The improved HIR additionally utilizes a higher efficiency reflector coating. These technology options are discussed in chapter 3 of this TSD.

5.4.4 Efficacy Levels

DOE adopted an equation-based approach to establish ELs for IRLs, reflecting the relationship between efficacy and wattage. DOE developed a continuous equation that specifies a

^q For IRLs, the rated efficacy is the catalog initial lumen output divided by catalog wattage.

minimum efficacy requirement across wattages and represents the potential efficacy a lamp achieves using a particular design option. The technology contour line represents the same IRL design option across the wattage range of the entire product class. For example, the EL based on an HIR lamp is a curve rather than a step function, and denotes an HIR standard at all wattages.

For IRLs in the representative product class, DOE observed a natural efficacy division in the marketplace corresponding to the design option utilized to increase lamp efficacy. DOE considered this efficacy division in selecting an EL by using the efficacies of commercially available lamps as a guide.

DOE also observed lifetime changes for different technologies. For example, a halogen lamp typically has a lifetime of around 1,500 hours, while an HIR lamp typically has a lifetime of 2,500 – 4,400 hours. DOE considered the possibility that manufacturers would produce lamps with a shorter lifetime than the baseline lamps in order to increase efficacy. To account for this scenario, DOE determined performance characteristics and prices for a model lamp that meets EL 1 by shortening lifetime rather than using more efficient design options. To calculate the performance characteristics of the model lamp, DOE calculated the minimum lumens necessary to meet EL 1 for a lamp with the same wattage as the baseline lamp. DOE then calculated the shortened lifetime necessary for the baseline lamp to achieve this minimum lumen output by using equations from the Illuminating Engineering Society of North America (IESNA) Lighting Handbook¹ that relate lifetime, lumens, and wattage. DOE assumed that the cost of the lamp with a shortened lifetime at EL 1 was equivalent to the cost of the baseline lamp because the lamp would utilize the same technology. These modeled lamps were incorporated in shortened lifetime scenarios analyzed in the shipments analysis (see chapter 11 of this TSD), as a sensitivity in the LCC analysis (see appendix 8B of this TSD), and as a sensitivity in the manufacturer impact analysis (MIA) (see appendix 13C of this TSD).

DOE selected representative units for each EL using information in manufacturer catalogs. DOE also reviewed publicly available lamp efficacy data submitted to DOE by manufacturers to show compliance with existing energy conservation standards.^r DOE notes that there is a limited amount of publicly available compliance information for lamps covered under this rulemaking. DOE found there to be compliance data for only 51 percent of covered IRL products compliant with the July 2012 standards

In general terms, DOE based EL 1 on the following design options:

EL 1: This efficacy level can be achieved by either an HIR lamp with a lifetime of 2,500 hours or an improved HIR lamp that may utilize improvements in reflector coatings with a lifetime of 4,200 hours.

By analyzing manufacturer compliance reports, DOE found that efficacies of lamps when reported for the purpose of compliance often vary from catalog values. DOE adjusted the initial EL for IRLs such that commercially available IRLs using design options represented by the EL

^r The publicly available compliance information for IRLs can be found in DOE's Compliance Certification Database available here: www.regulations.doe.gov/certification-data/.

would comply with the EL. Specifically, DOE adjusted EL 1 based on the reported efficacy of a PAR38 HIR lamp and a PAR38 improved HIR lamp.

Table 5.4.3 provides detailed information on the IRL representative lamps used in the engineering analysis and subsequent analyses.

Table 5.4.3 IRL Representative Lamps

Efficacy Level	Lamp Type	Descriptor	Wattage	Efficacy*	Initial Light Output	Lifetime
			W	lm/W	lm	hr
Baseline	PAR38	Improved Halogen	60	17.8	1,070	1,500
EL 1	PAR38	HIR	55	18.5	980	2,500
EL 1	PAR38	Improved HIR	55	18.5	1,120	4,200

*Efficacy values are based on data from DOE's certification database.

Figure 5.4.1 presents the compliance data for the representative lamp units used to develop the IRL EL. The triangle indicates the representative units.

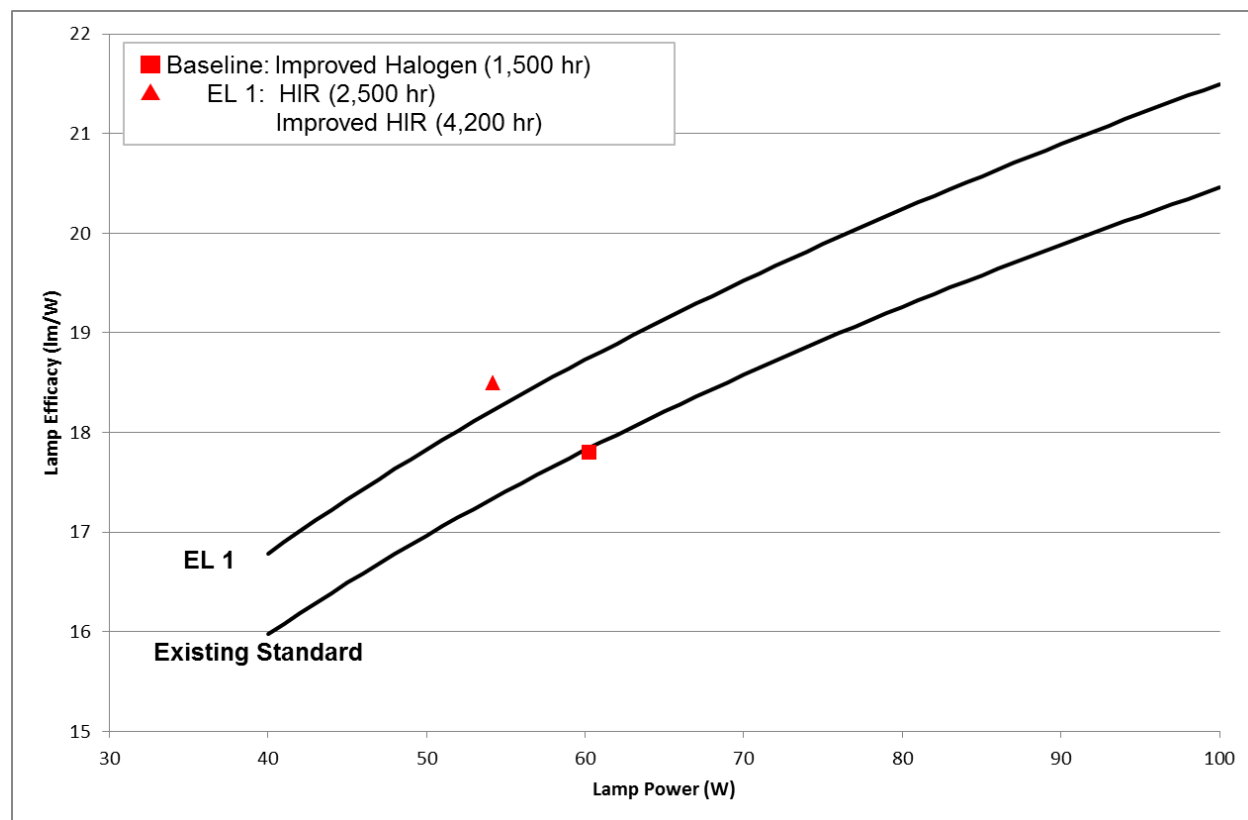


Figure 5.4.1 Compliance Report Data for Standard Spectrum, Large Diameter, Low Voltage IRLs

Table 5.4.4 summarizes the resulting efficacy requirements at EL 1 after accounting for compliance report data.

Table 5.4.4 EL 1 for Standard Spectrum, Large Diameter, Low Voltage IRLs

Efficacy Level	Efficacy Requirement <i>lm/W</i>
EL 1	$6.2P^{0.27}$

P = rated wattage

5.4.5 Scaling to Product Classes Not Analyzed

DOE identified and selected a representative product class on which to concentrate its analytical effort. DOE considered this product class as representative primarily due to its high market volume. The following sections discuss how DOE scaled ELs from the analyzed product class to those product classes not directly analyzed.

5.4.5.1 Modified Spectrum

DOE did not directly analyze modified spectrum IRLs, but established ELs for this product class by scaling from the ELs developed for the standard spectrum product class. DOE developed a relationship between the performance of standard spectrum and modified spectrum IRLs. As with higher CCT GSFLs, modified spectrum IRLs achieve their modified spectra through selective filtering, thereby inherently lowering their efficacies. Manufacturers achieve this specific spectrum in modified spectrum IRLs by applying a coating, or introducing neodymium or other additives into the cover glass of the IRL. Manufacturers may change the thickness of the coating or the content of neodymium to modify the spectrum to different degrees, and this modification changes the lumen output of the IRL. In the 2009 Lamps Rule, DOE assessed the efficacy differences between standard and modified spectrum IRLs by measuring the efficacies of commercially available standard and modified spectrum lamps. 74 FR 34080 (July 14, 2009)⁵ DOE correlated the measured color point data of the lamps with lamp light output reduction and lamp spectral power distribution. By analyzing the data, DOE established that a reduction of 15 percent from the standard spectrum ELs would be appropriate for modified spectrum IRLs. See appendix 5B of this TSD for further details on DOE's modified spectrum IRL analysis.

At the time of the preliminary analysis for this rulemaking DOE found a limited number of modified spectrum products on the market and confirmed these lamps had an efficacy reduction of 15 percent from standard spectrum products. Thus, DOE is proposing a 15 percent reduction from standard spectrum to modified spectrum lamps. Table 5.4.5 shows a summary of the EL for modified spectrum IRLs with diameters greater than 2.5 inches and operating voltages less than 125 V.

⁵ Information regarding the 2009 Lamps Rule can be found on [regulations.gov](http://www.regulations.gov), docket number EERE-2006-STD-0131 at www.regulations.gov/#!docketDetail;D=EERE-2006-STD-0131.

Table 5.4.5 EL 1 for Modified Spectrum, Large Diameter, Low Voltage IRLs

EL	Efficacy Requirement <i>lm/W</i>		Reduction
	Standard Spectrum	Modified Spectrum	
1	6.2P ^{0.27}	5.2P ^{0.27}	15.0%

P = rated wattage

5.4.5.2 Diameters Less Than or Equal To 2.5 Inches

DOE did not directly analyze IRLs with diameters less than or equal to 2.5 inches but established ELs for this product class by scaling from the ELs developed for the IRL product class with diameters greater than 2.5 inches. DOE developed a relationship between the performance of small diameter and large diameter IRLs. A smaller-diameter IRL has an inherently lower optical efficacy than a larger-diameter lamp given a similar filament size. To determine an appropriate scaling factor for IRLs with diameters less than or equal to 2.5 inches, DOE examined the inherent efficacy differences between the halogen PAR20 lamp (the most common IRL with a diameter less than or equal to 2.5 inches) and the halogen PAR30 or PAR38 with approximately the same features as the PAR20 except for diameter.^t DOE compared catalog efficacy data of each lamp type from several lamp manufacturers and found that the reduction in efficacy caused by the smaller lamp diameter was approximately 12 percent for IRLs.

DOE acknowledges that diameter may impact the type of burner that is used within a lamp. Single-ended burners feature a lead wire inside of the burner that carries current between the filament and the electrical connection in the IRL's base. The presence of this wire inside of the burner prevents a certain amount of energy from reaching the burner wall and being reflected (recycled) back to the burner filament. Large diameter IRLs with HIR technology may feature a double-ended HIR burner. A double-ended burner features a lead wire outside of the burner, where it does not interfere with the reflectance of energy from the burner wall back to the burner filament. However, the double-ended HIR burner configuration does not generally fit into a PAR20 lamp due to its reduced size. Fitting a double-ended burner into a small diameter lamp would require changes to the physical shape of the lamp, specifically requiring an extension of the reflector lens. While the modified lamp may still meet ANSI standards for a small diameter lamp such as a PAR20, it would be larger than any PAR20 lamps sold in the past and those that are currently installed. Because the lamp shape would be different from the standard sizes of small diameter lamps that are currently commercially available, the modified lamp may not fit in existing structures. Past a certain wattage threshold, heat dissipation in lamps with a smaller envelope using a double-ended burner could also become an issue. Further, if the double-ended burner could fit into a small diameter lamp, it would be difficult to place the burner/filament in the optimal position. Thus, DOE developed the efficacy requirements for small diameter IRLs by assuming that the double-ended burner technology could not be used and incorporated a scaling factor for single-ended burner.

^t DOE notes that the small diameter lamps used for this analysis were 39 W which are not covered under energy conservation standards.

To determine the efficacy reduction that would result from using a single-ended burner instead of a double-ended burner in a lamp, in the 2009 Lamps Rule DOE obtained a commercially available single-ended HIR burner and measured the location of the lead wire inside of the burner. DOE then developed a model that computed how much energy is prevented from being reflected against the burner wall and recycled due to the “shadowing effect” of the lead wire inside of the burner. DOE was also able to determine the slight change in IRL power consumption due to the reduction in energy recycling. Finally, DOE simulated manufacturing variability by modeling the effects of changing the burner dimensions and lead wire positioning by small amounts. Using the modeled data, DOE computed that an efficacy reduction of approximately 3.5 percent would result from the usage of a single-ended burner instead of a double-ended burner in a lamp. DOE conducted a similar analysis for this NOPR and concluded that there is a 3.5 percent loss in efficacy between a double-ended and single-ended burner.

The 3.5-percent reduction for a single-ended burner is in addition to the 12-percent-lower optical efficacy for small diameter IRLs compared to large diameter IRLs. Therefore, DOE is considering a scaling factor of 15.5 percent with 12 percent based on the impact of the diameter and an additional 3.5 percent based on the use of less efficient single-ended burners in small diameter lamps. Table 5.4.6 shows a summary of the EL for standard spectrum IRLs with diameters less than or equal to 2.5 inches and operating voltages less than 125 V.

Table 5.4.6 EL 1 for Standard Spectrum, Small Diameter, Low Voltage IRLs

EL	Efficacy Requirement <i>lm/W</i>		Reduction
	≥ 2.5 Inches	< 2.5 Inches	
1	6.2P ^{0.27}	5.2P ^{0.27}	15.5%

P = rated wattage

5.4.5.3 Operating Voltages Greater Than or Equal to 125 Volts

As discussed in chapter 3 of this TSD, DOE is considering separate product classes for lamps rated at 120 V and those rated at 130 V. DOE notes that most consumers operate 130 V lamps at 120 V, which slightly decreases their efficacy but increases their lifetime. In the 2009 Lamps Rule, DOE developed a scaling factor for the 130 V product class that would require 130 V lamps to use the same technology and possess the same general performance characteristics as 120 V lamps operated at 120 V. To perform this analysis, DOE used catalog data for 130 V lamps operated at 130 V and the same lamps operated at 120 V.

Firstly, DOE found that while there may be a slight decrease in efficacy, the lifetime of a 130 V lamp is doubled when it is operated at 120 V, giving it an advantage over 120 V rated lamps. Therefore, using the IESNA Lighting Handbook² equations that relate lifetime, lumens, and wattage to voltage of incandescent lamps, DOE determined the increase in efficacy of 130 V rated lamps if their additional lifetime over that of 120 V lamps were instead used to increase their efficacy. The equations DOE used from the IESNA Lighting Handbook are as follows:

$$\frac{life}{LIFE} = \left(\frac{VOLTS}{volts} \right)^d \quad \text{Eq. 5.1}$$

$$\frac{\text{lumens}}{\text{LUMENS}} = \left(\frac{\text{volts}}{\text{VOLTS}} \right)^k \quad \text{Eq. 5.2}$$

$$\frac{\text{watts}}{\text{WATTS}} = \left(\frac{\text{volts}}{\text{VOLTS}} \right)^n \quad \text{Eq. 5.3}$$

Capital letters represent normal rated values while lower-case letters represent changed values. By using published manufacturer literature on lumen, wattage, and voltage ratings, DOE found in the 2009 Lamps Rule that the most typical values for d, k, and n in the above equations for the IRLs analyzed are as follows: d=8.7, k=3.4, n=1.6.

Secondly, because 130 V lamps operated at 120 V are in a partially dimmed state, DOE calculated what the full (non-dimmed) light output would need to be of the 130 V lamp operated at 120 V to match the light output of a 120 V lamp operated at 120 V. DOE thus used the IESNA Lighting Handbook equations to determine what the lumen output of the 130 V lamp operated at 120 V would be if it had the same characteristics as a 120 V lamp operated at 120 V.

Both the effects of lifetime and partially dimmed state on efficacy were used to determine a 15 percent scaling factor was necessary. Therefore, DOE implemented a 15 percent increase to scale from the < 125 V product class to the ≥ 125 V product class in the 2009 Lamps Rule.

DOE believes that the analysis from the 2009 Lamps Rule is still applicable. Thus, DOE is considering maintaining the 15 percent increase in this rulemaking. Table 5.4.7 shows a summary of the EL for standard spectrum IRLs with diameters greater than 2.5 inches and operating voltages greater than or equal to 125 V.

Table 5.4.7 EL 1 for Standard Spectrum, Large Diameter, High Voltage IRLs

EL	Efficacy Requirement <i>lm/W</i>		Increase
	< 125 Volts	≥ 125 Volts	
1	6.2P ^{0.27}	7.1P ^{0.27}	15.0%

P = rated wattage

5.4.6 Summary of All Efficacy Levels for Covered IRLs

In analyzing commercially available IRLs, DOE found each scaling factor (spectrum, diameter, and voltage) to be independent. To scale from the representative product class to a scaled product class, DOE applied each scaling factor that corresponded to the differences between the two classes by multiplying the representative product class coefficient by all applicable scaling factors and rounding the result. In applying scaling factors, DOE rounded the coefficient of the required efficacy down to the nearest tenth where applicable. Table 5.4.8 shows a summary of the ELs for all IRLs covered by this rulemaking. The representative IRL product class is indicated by gray shading.

Table 5.4.8 Summary of Efficacy Levels for Covered IRLs

Lamp Type	Diameter	Voltage	EL 1
Standard spectrum	> 2.5 inches	≥ 125 V	$7.1P^{0.27}$
		< 125 V	$6.2P^{0.27}$
	≤ 2.5 inches	≥ 125 V	$6.0P^{0.27}$
		< 125 V	$5.2P^{0.27}$
Modified spectrum	> 2.5 inches	≥ 125 V	$6.0P^{0.27}$
		< 125 V	$5.2P^{0.27}$
	≤ 2.5 inches	≥ 125 V	$5.1P^{0.27}$
		< 125 V	$4.4P^{0.27}$

P = rated wattage

REFERENCES

1 Rea, M. S., ed., *The IESNA Lighting Handbook: Reference and Application, 9th Edition*. New York: Illuminating Engineering Society of North America. IESNA (2000).

2 Ibid.

CHAPTER 6. ENERGY USE CHARACTERIZATION

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CHAPTER 6. ENERGY USE CHARACTERIZATION

6.1 PURPOSE OF THE DOCUMENT

This chapter presents the methodology the U.S. Department of Energy (DOE) follows to estimate the annual energy consumption of the lamp and lamp-and-ballast designs DOE considers in the rulemaking analyses. The results of this analysis, which represent typical energy consumption in the field, are critical inputs to the life-cycle cost (LCC) and payback period (PBP) analyses, described in chapter 8 of this notice of proposed rulemaking (NPR) technical support document (TSD), and the national impact analysis (NIA), described in chapter 12 of this TSD. DOE utilizes information on annual energy consumption to determine the potential energy and operating cost savings to consumers from the use of more-efficient products.

DOE determined the annual energy consumption of the lamp and lamp-and-ballast designs using information on their rated power (*i.e.*, the rate of energy they consume) and the way consumers use them (*i.e.*, operating hours per year). The engineering analysis (chapter 5 of this TSD) discusses the power ratings of lamp and lamp-and-ballast designs. The following sections discuss the inputs and calculations DOE used to develop annual operating hours and annual energy consumption for the products considered in this analysis.

6.2 OPERATING HOURS

To characterize the country's average use of lighting for a typical year, DOE developed annual operating hours by market sector and lamp type (*i.e.*, general service fluorescent lamps [GSFLs] and incandescent reflector lamps [IRLs]). For the LCC, DOE accounted for variability in operating hours by developing a distribution of operating hours in the LCC spreadsheet for each lamp type. The operating hour distributions capture variation by building type across 13 census divisions and large states for all market sectors analyzed.^a

In conjunction with data from the 2010 U.S. Lighting Market Characterization (LMC),¹ DOE used data from the Energy Information Administration's (EIA's) 2003 Commercial Building Energy Consumption Survey (2003 CBECS),² 2009 Residential Energy Consumption Survey (2009 RECS),³ and 2006 Manufacturer Energy Consumption Survey (2006 MECS).⁴ These EIA studies provide information on the distribution and square footage of U.S. buildings by building type and census division. The LMC, which is based on thousands of building audits and surveys, provides national-level data on annual operating hours by building type and lamp type for all sectors as well as the distribution of lamp types for each building type. The operating hours are broken down by room type for the residential sector.^b

^a Census divisions include New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific. Large states include California, Florida, New York, and Texas. Sectors include residential, commercial, and industrial for GSFLs and residential and commercial for IRLs.

^b Residential sector residence types include single family detached, single family attached, multifamily, and mobile home. Residential sector room types include basement(s), bathroom(s), bedroom(s), closet(s), dining room(s), exterior(s), garage(s), hall(s), kitchen(s), laundry/utility room(s), living/family room(s), office(s), other/unknown.

DOE associated LMC data with EIA data to derive annual operating hours by census division and large states. This allowed DOE to correlate the electricity price distribution and sales tax distribution (see chapter 8 of this TSD) with the operating hour distribution in the LCC spreadsheet. The following paragraphs describe the data sources that DOE used to develop annual operating hours by sector.

For the residential sector, DOE used RECS building data and LMC residential sector operating hour data to develop average annual operating hours for IRLs and GSFLs. The 2009 RECS data indicates the number of buildings of each type for each division or large state. The LMC indicates the occurrence of IRLs and GSFLs in certain room types within a given building type and the number of lamps and lamp operating hour characteristics in these rooms. DOE used aggregated data from the LMC to calculate average annual operating hours for GSFLs and IRLs per building type and the average number of lamps per building type, which is shown in Eq. 6.1.

$$\begin{aligned} & \text{GSFLs per Residential Building for Building Type } j \\ &= \sum_k \left[\left(\frac{\text{All Lamps}}{\text{Room}} \right)_k \times \left(\frac{\text{GSFLs/Room}}{\text{All Lamps/Room}} \right)_k \right] \end{aligned}$$

Eq. 6.1

Where:

k = a room type.

DOE then calculated the probability of a GSFL within each housing type for each census division or large state using the number of buildings of that type calculated using RECS data and the average GSFLs per building type calculated using LMC data, which is shown in Eq. 6.2. Similarly, DOE calculated the probability of an IRL within each housing type for each census division or large state using the number of buildings of that type calculated using RECS data and the average IRLs per building type calculated using LMC data. DOE then used the lamp probability for each building type and the annual operating hours from the LMC to calculate a weighted average of residential operating hours for all building types.

Commercial building types include education, food service, food store, health care – inpatient, health care – outpatient, lodging, offices (non-medical), public assembly, public order and safety, religious worship, retail – mall & non-mall, services, warehouse and storage, and other. Vacant buildings were not included in the commercial sector analysis. Industrial building types include apparel, beverage and tobacco products, chemicals, computer and electronic products, electrical eq., appliances & components, fabricated metal products, food, furniture and related products, leather and allied products, machinery, nonmetallic mineral products, paper, petroleum and coal products, plastics and rubber products, primary metals, printing and related support, textile mills, textile product mills, transportation equipment, wood products, and miscellaneous.

Probability of Residential Building Type j for GSFLs

$$= \sum_{i=1}^{13} \left[\left(\frac{\text{Lamps}}{\text{Building}} \right)_j \times \text{Total Buildings}_i \right]$$

Eq. 6.2

Where:

i = a census division or large state.

For the residential sector, DOE chose to aggregate operating hour data to the building level, rather than to the room level, because DOE believes this approach better represents the impact on an individual consumer. However, because the LCC and PBP results are highly dependent on operating hours and there is a large range of hours across room types, DOE does use operating hour data at the room level to perform LCC sensitivity analyses for IRLs (see appendix 8B of this TSD).

For the commercial sector, DOE used the operating hours by lamp type, estimated U.S. lamp inventory, and daily operating hours by building type from the LMC to calculate the annual operating hours by building type for GSFLs and IRLs. DOE used 2003 CBECS data to calculate the square feet of each building type within each census division or large state. DOE determined the average lamps per square foot and the percentage of lamps that are linear fluorescent from the LMC. DOE then calculated the probability of a GSFL within each building type for each census division or large state, which is shown in Eq. 6.3. Similarly, for IRLs DOE determined the average lamps per square foot that are halogen from the LMC. DOE then calculated the probability of an IRL within each building type for each census division or large state. Using the probability and annual operating hours of each building type, DOE calculated a weighted average of commercial operating hours for all building types.

For the industrial sector, DOE used the operating hours by lamp type, estimated U.S. lamp inventory, and daily operating hours by building type from the LMC to calculate the annual operating hours by building type for GSFLs. DOE used 2006 MECS data to calculate the square feet of each building type. DOE determined the average lamps per square foot and the percentage of lamps that are linear fluorescent from the LMC. DOE then calculated the probability of a GSFL within each building type, which is shown in Eq. 6.3. DOE then used the annual operating hours calculated from the LMC and the GSFL probability to calculate a weighted average of industrial operating hours for all building types. Table 6.2.1 summarizes the weighted-average operating hours per lamp type per sector. Due to low market share (less than 1 percent, as indicated in the 2010 LMC)⁵, DOE did not assess energy use for IRLs in the industrial sector.

Probability of Commercial or Industrial Building Type j for GSFLs

$$= \sum_{i=1}^{13} \left[\text{Total Square Feet}_{i,j} \times \left(\frac{\text{All Lamps}}{\text{Square Foot}} \right)_j \times \left(\frac{\text{GSFL Lamps}}{\text{All Lamps}} \right)_j \right]$$

Eq. 6.3

Where:

i = a census division or large state.

Table 6.2.1 Average Operating Hours by Sector and Lamp Type

Sector	Lamp Type	Average Annual Operating Hours <i>hr/year</i>
Residential	GSFL	634
	IRL	763
Commercial	GSFL	4,065
	IRL	4,532
Industrial	GSFL	4,587

Figure 6.2.1 and Figure 6.2.2 display the probability of an IRL or GSFL in each building type in the residential sector. Figure 6.2.3 and Figure 6.2.4 display the annual operating hours DOE uses for IRLs and GSFLs, respectively, in the residential sector for each building type. DOE used these annual operating hours in the calculation of annual energy consumption.

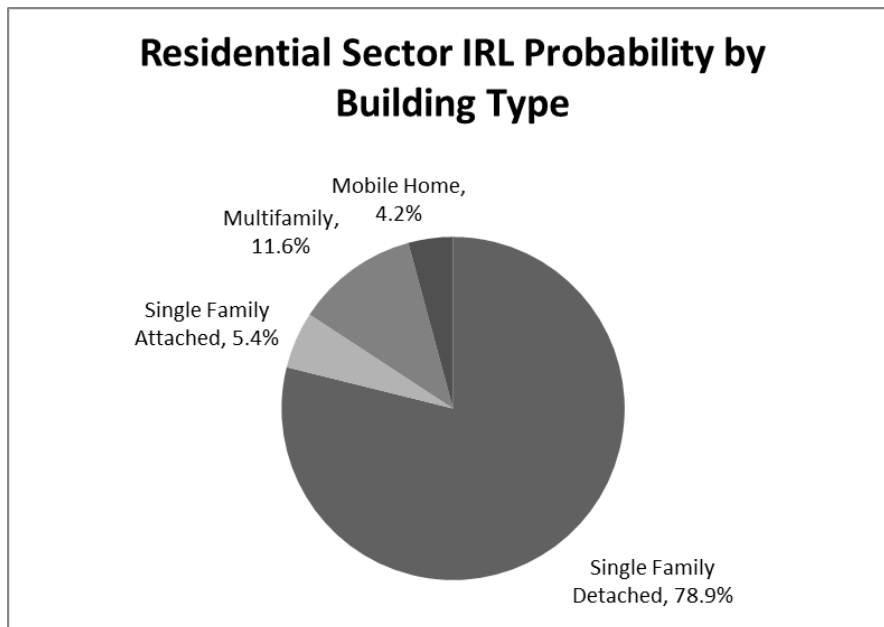


Figure 6.2.1 Residential Sector IRL Probability by Building Type

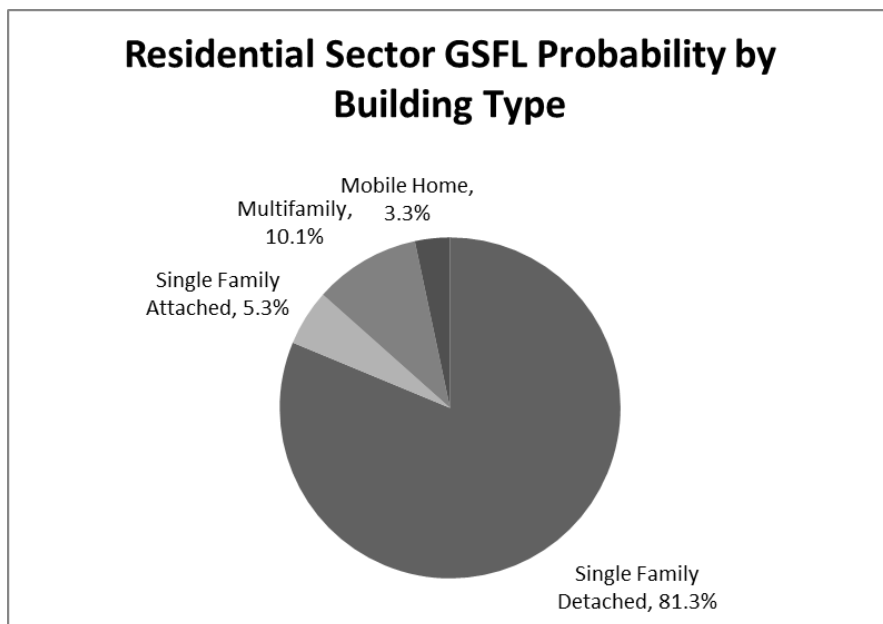


Figure 6.2.2 Residential Sector GSFL Probability by Building Type

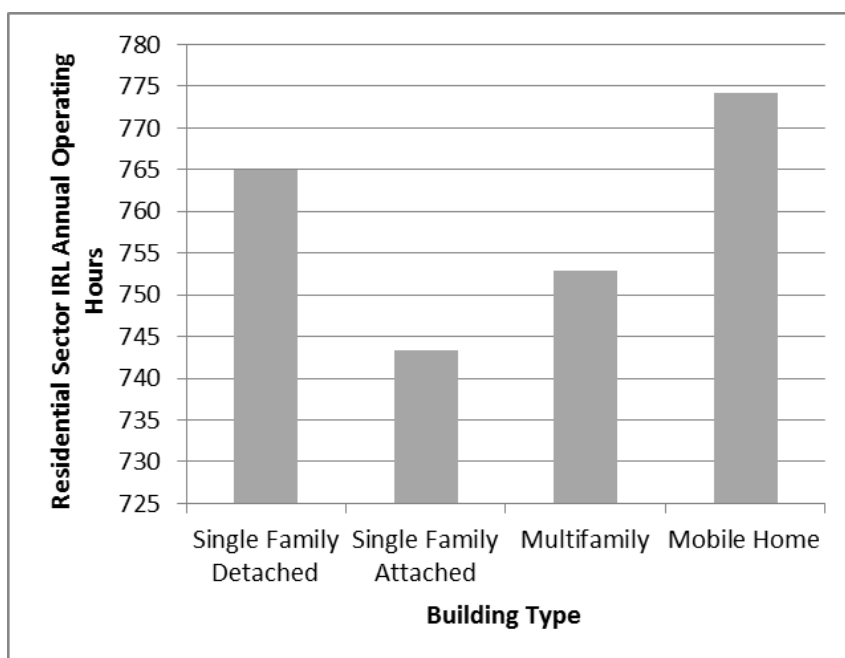


Figure 6.2.3 Residential Sector IRL Annual Operating Hour Distribution by Building Type

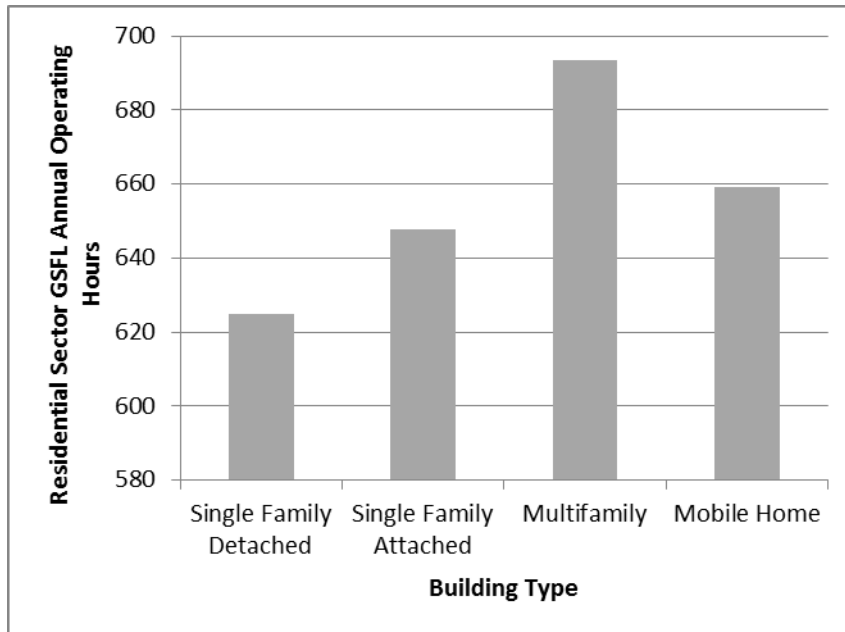


Figure 6.2.4 Residential Sector GSFL Annual Operating Hour Distribution by Building Type

Figure 6.2.5 and Figure 6.2.6 display the probability of an IRL or GSFL in each building type in the commercial sector. Figure 6.2.7 and Figure 6.2.8 display the annual operating hour distributions for IRLs and GSFLs, respectively, operating in the commercial sector. DOE used this distribution of annual operating hours in the calculation of annual energy consumption.

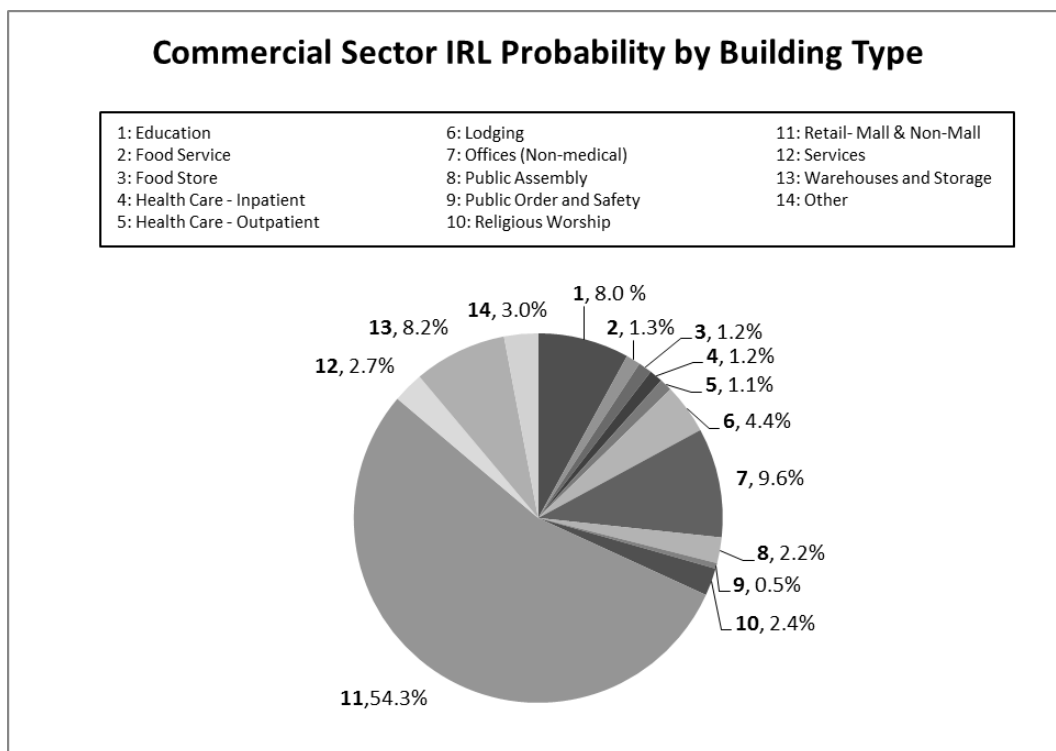


Figure 6.2.5 Commercial Sector IRL Probability by Building Type

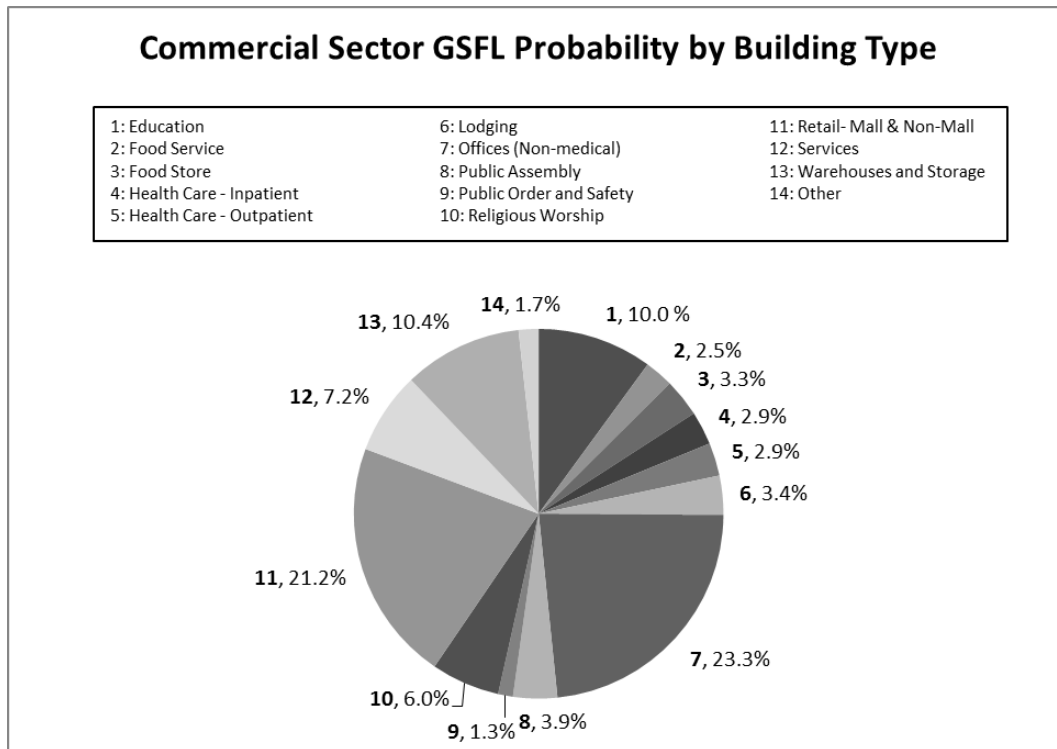


Figure 6.2.6 Commercial Sector GSFL Probability by Building Type

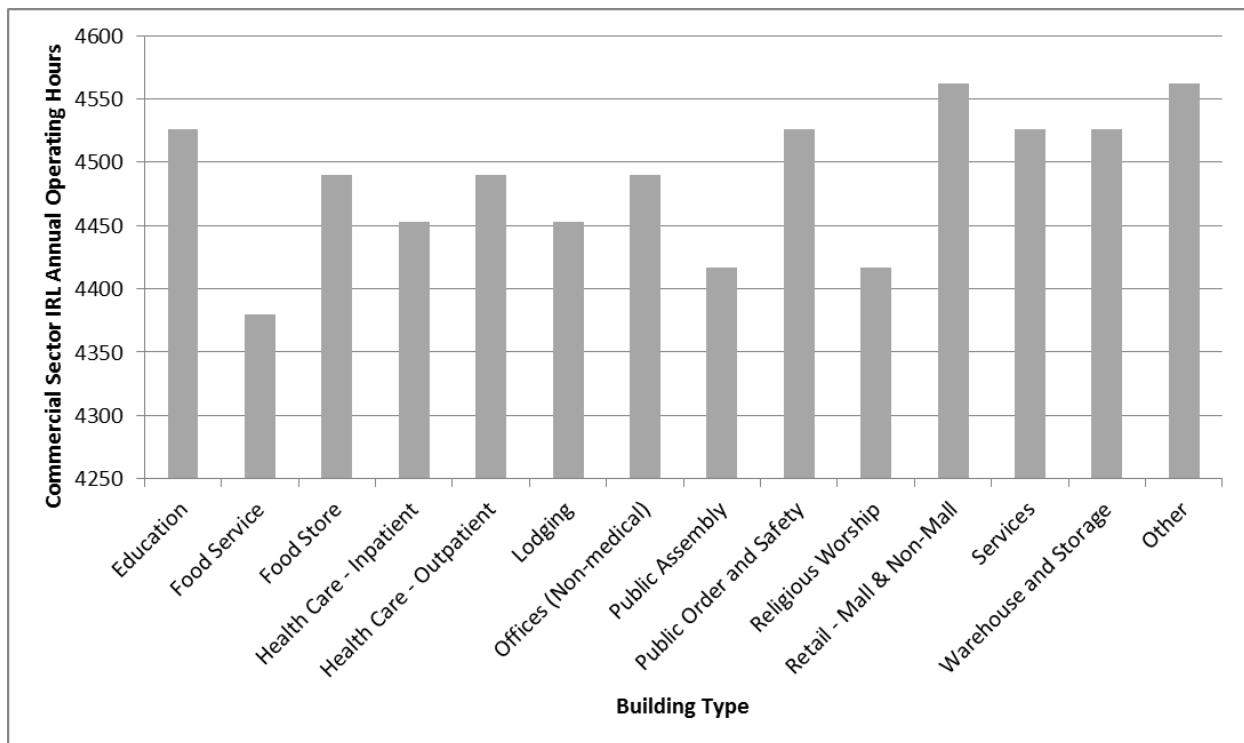


Figure 6.2.7 Commercial Sector IRL Annual Operating Hour Distribution by Building Type

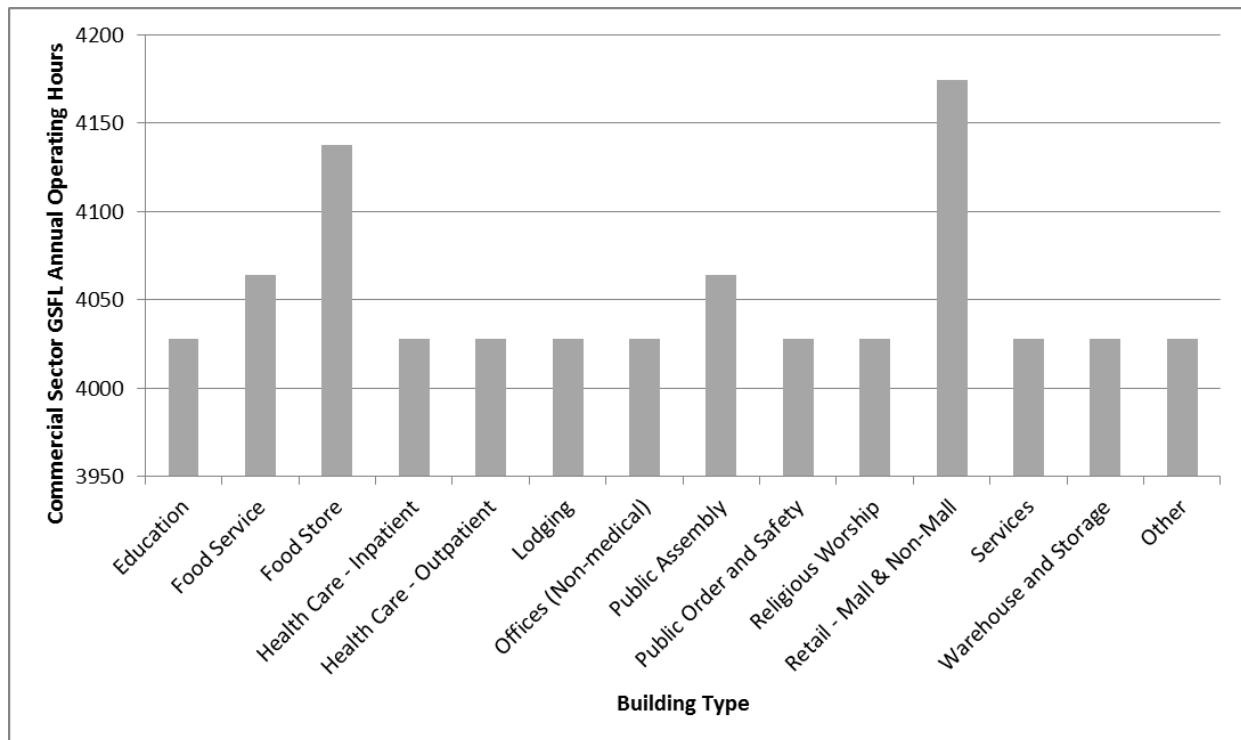


Figure 6.2.8 Commercial Sector GSFL Annual Operating Hour Distribution by Building Type

Figure 6.2.9 displays the probability of a GSFL in each building type in the industrial sector. Figure 6.2.10 displays the annual operating hour distribution for GSFLs operating in the industrial sector. DOE used this distribution of annual operating hours in the calculation of annual energy consumption.

Industrial Sector GSFL Probability by Building Type

1: Apparel	9: Leather and Allied Products	17: Textile Mills
2: Beverage and Tobacco Products	10: Machinery	18: Textile Product Mills
3: Chemicals	11: Nonmetallic Mineral Products	19: Transportation Equipment
4: Computer and Electronic Products	12: Paper	20: Wood Products
5: Electrical Eq. Appliances & Components	13: Petroleum and Coal Products	21: Miscellaneous
6: Fabricated Metal Products	14: Plastics and Rubber Products	
7: Food	15: Primary Metals	
8: Furniture and Related Products	16: Printing and Related Support	

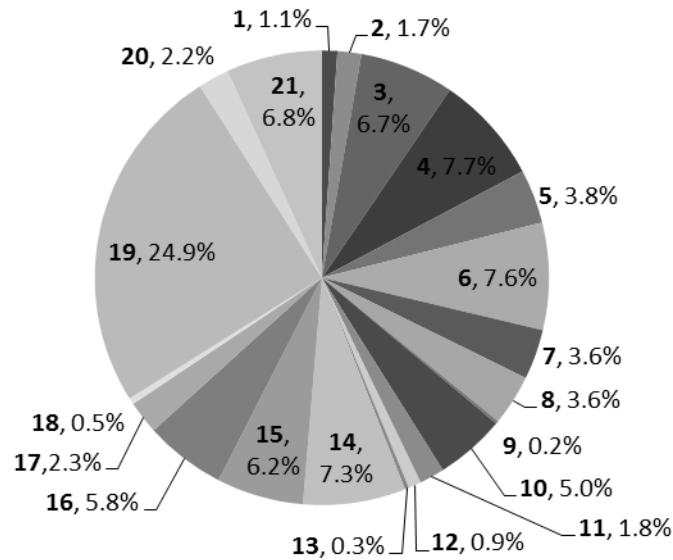


Figure 6.2.9 Industrial Sector GSFL Probability by Building Type

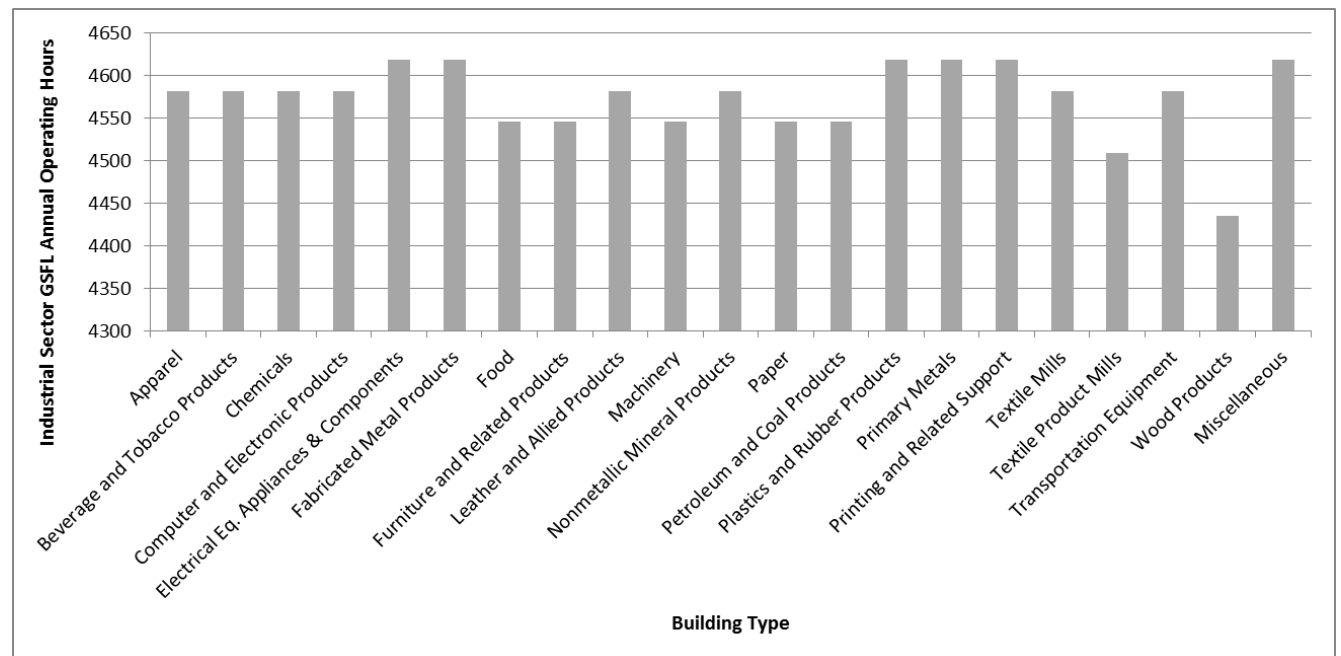


Figure 6.2.10 Industrial Sector GSFL Annual Operating Hour Distribution by Building Type

6.3 LIGHTING CONTROLS

DOE evaluated the effects of lighting controls on energy use by examining the impact of dimmers on the annual energy consumption of both GSFLs and IRLs. See appendix 6A of this TSD for a discussion of how DOE accounted for the use of dimmers and see appendix 8B of this TSD for the LCC savings of GSFLs and IRLs operated on dimming systems.

6.4 RESULTS OF THE ENERGY USE CHARACTERIZATION

This section presents the annual energy use estimates for GSFLs and IRLs. DOE calculated the annual energy consumption using the average annual operating hours (see section 6.2) and power rating estimates of the lamp or lamp-and-ballast systems derived in the engineering analysis (see chapter 5 of this TSD). DOE used the annual energy consumption results in the LCC and PBP analyses and the NIA to calculate the operating cost of systems and estimate the potential energy savings of efficacy levels (ELs).

6.4.1 General Service Fluorescent Lamps

Using annual operating hours and system input power or power rating of GSFL lamp or lamp-and-ballast systems, DOE calculated the annual energy consumption of the entire lamp-and-ballast system. The tables below present: (1) the system input power for all GSFL systems DOE assessed in the LCC and PBP analysis; and (2) average annual energy consumption per lamp-and-ballast system using the U.S. weighted average of annual operating hours in each sector. DOE calculated the annual energy consumption based on the U.S. weighted-average annual operating hours for GSFLs in the residential, commercial, and industrial sectors, which are 634 hours, 4,065 hours, and 4,587 hours, respectively. Appendix 6A of this TSD presents the energy consumption rates for systems operated on dimmers.

As discussed in the engineering analysis, DOE paired lamps with ballasts of different starting methods and of different ballast factors (BFs), creating a number of system designs. See chapter 5 of this TSD for more discussion of the lamp-and-ballast systems.

Table 6.4.1 Annual Energy Consumption for the 4-Foot Medium Bipin T8 GSFL 2-Lamp Instant Start System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.88BF32.5 Elec*	56.0	227.4	256.7
	EL 1	0.88BF32.5 Elec	56.0	227.4	256.7
	EL 2	0.88BF26.6 Elec	46.9	190.6	215.1
	EL 2	0.88BF32.5 Elec	56.0	227.4	256.7
	EL 2	0.88BF28.4 Elec	50.3	204.4	230.7
Lamp-and-Ballast Replacement	Baseline	0.88BF32.5 Elec	55.2	224.5	253.4
	EL 1	0.78BF32.5 Elec	49.4	200.8	226.6
	EL 2	0.88BF26.6 Elec	46.3	188.0	212.2
	EL 2	0.77BF32.5 Elec	48.3	196.5	221.8
	EL 2	0.87BF28.4 Elec	48.8	198.2	223.7

W = watts

kWh = kilowatt hours

*“0.88BF32.5 Elec” indicates a lamp-and-ballast system consisting of a 32.5W lamp paired with an electronic ballast of a 0.88 ballast factor.

Table 6.4.2 Annual Energy Consumption for the 4-Foot Medium Bipin T8 GSFL 2-Lamp Programmed Start System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 1	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 2	0.88BF26.6 Elec	47.0	191.0	215.6
	EL 2	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 2	0.88BF28.4 Elec	50.4	204.7	231.0
Lamp-and-Ballast Replacement	Baseline	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 1	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 1	0.72BF32.5 Elec	47.1	191.3	215.9
	EL 2	0.88BF26.6 Elec	47.0	191.0	215.6
	EL 2	0.88BF32.5 Elec	56.0	227.5	256.7
	EL 2	0.72BF32.5 Elec	47.1	191.3	215.9
	EL 2	0.88BF28.4 Elec	50.4	204.7	231.0

Table 6.4.3 Annual Energy Consumption for the 4-Foot Medium Bipin T8 GSFL 4-Lamp Instant Start System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.87BF32.5 Elec	108.0	439.0	495.5
	EL 1	0.87BF32.5 Elec	108.0	439.0	495.5
	EL 2	0.87BF26.6 Elec	90.4	367.5	414.7
	EL 2	0.87BF32.5 Elec	108.0	439.0	495.5
	EL 2	0.87BF28.4 Elec	97.0	394.3	445.0
Lamp-and-Ballast Replacement	Baseline	0.87BF32.5 Elec	107.1	435.4	491.4
	EL 1	0.78BF32.5 Elec	96.8	393.6	444.3
	EL 2	0.87BF26.6 Elec	89.6	364.3	411.2
	EL 2	0.74BF32.5 Elec	93.7	380.7	429.7
	EL 2	0.87BF28.4 Elec	96.2	391.0	441.3

Table 6.4.4 Annual Energy Consumption for the 4-Foot Medium Bipin T8 GSFL 4-Lamp System Programmed Start System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.89BF32.5 Elec	111.0	451.3	509.4
	EL 1	0.89BF32.5 Elec	111.0	451.3	509.4
	EL 2	0.89BF26.6 Elec	93.1	378.5	427.1
	EL 2	0.89BF32.5 Elec	111.0	451.3	509.4
	EL 2	0.89BF28.4 Elec	99.8	405.8	458.0
Lamp-and-Ballast Replacement	Baseline	0.89BF32.5 Elec	111.0	451.3	509.4
	EL 1	0.87BF32.5 Elec	106.1	431.2	486.7
	EL 2	0.89BF26.6 Elec	93.1	378.5	427.1
	EL 2	0.87BF32.5 Elec	106.1	431.2	486.7
	EL 2	0.87BF28.4 Elec	95.3	387.4	437.2

Table 6.4.5 Annual Energy Consumption for the 4-Foot Medium Bipin T8 GSFL 2-Lamp Instant Start System, Residential Sector

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption
				Residential
			<i>W</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.87BF32.5 Elec	56.5	35.9
	EL 1	0.87BF32.5 Elec	56.5	35.9
	EL 2	0.87BF26.6 Elec	47.4	30.1
	EL 2	0.87BF32.5 Elec	56.5	35.9
	EL 2	0.87BF28.4 Elec	50.8	32.2
Lamp-and-Ballast Replacement	Baseline	0.87BF32.5 Elec	56.5	35.9
	EL 1	0.83BF32.5 Elec	53.7	34.0
	EL 2	0.87BF26.6 Elec	47.4	30.1
	EL 2	0.83BF32.5 Elec	53.7	34.0
	EL 2	0.83BF28.4 Elec	48.2	30.6

Table 6.4.6 Annual Energy Consumption for the 8-Foot T8 Single-Pin Slimline GSFL 2-Lamp System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.87BF60.1 Elec	106.8	433.9	489.7
	EL 1	0.87BF60.1 Elec	106.8	433.9	489.7
	EL 2	0.87BF60.1 Elec	106.8	433.9	489.7
	EL 2	0.87BF54.0 Elec	101.2	411.5	464.4
	EL 2	0.87BF50.0 Elec	93.9	381.5	430.6
Lamp-and-Ballast Replacement	Baseline	0.87BF60.1 Elec	105.1	427.3	482.2
	EL 1	0.77BF60.1 Elec	93.9	381.6	430.6
	EL 2	0.77BF60.1 Elec	93.9	381.6	430.6
	EL 2	0.77BF54.0 Elec	89.0	361.8	408.3
	EL 2	0.87BF50.0 Elec	92.4	375.5	423.8

Table 6.4.7. Annual Energy Consumption for the 8-Foot T8 Recessed Double Contact High Output GSFL 2-Lamp System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	0.81BF84.0 Elec	148.4	603.4	680.9
	EL 1	0.81BF84.0 Elec	148.4	603.4	680.9
	EL 2	0.81BF84.0 Elec	148.4	603.4	680.9
Lamp-and-Ballast Replacement	Baseline	0.81BF84.0 Elec	148.4	603.4	680.9
	EL 1	0.81BF84.0 Elec	148.4	603.4	680.9
	EL 2	0.81BF84.0 Elec	148.4	603.4	680.9

Table 6.4.8 Annual Energy Consumption for the 4-Foot T5 Miniature Bipin Standard Output GSFL 2-Lamp System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	1.00BF27.8 Elec	60.4	245.5	277.0
	EL 1	1.00BF27.8 Elec	60.4	245.5	277.0
	EL 2	1.00BF27.8 Elec	60.4	245.5	277.0
	EL 2	1.00BF26.0 Elec	56.6	230.0	259.6
	EL 2	1.00BF25.0 Elec	54.5	221.4	249.9
Lamp-and-Ballast Replacement	Baseline	1.00BF27.8 Elec	60.4	245.5	277.0
	EL 1	0.85BF27.8 Elec	53.0	215.4	243.1
	EL 2	0.85BF27.8 Elec	53.0	215.4	243.1
	EL 2	0.85BF26.0 Elec	49.7	202.0	228.0
	EL 2	0.85BF25.0 Elec	47.9	194.6	219.6

Table 6.4.9 Annual Energy Consumption for the 4-Foot T5 Miniature Bipin High Output GSFL 2-Lamp System, Commercial and Industrial Sectors

Event Description	EL	Technology Option	System Input Power	Annual Energy Consumption	
				Commercial	Industrial
			<i>W</i>	<i>kWh</i>	<i>kWh</i>
Lamp Only Replacement	Baseline	1.00BF53.8 Elec	116.5	473.5	534.3
	EL 1	1.00BF53.8 Elec	116.5	473.5	534.3
	EL 1	1.00B49.0 Elec	106.4	432.4	488.0
	EL 1	1.00B47.0 Elec	102.2	415.2	468.6
Lamp-and-Ballast Replacement	Baseline	1.00BF53.8 Elec	116.5	473.5	534.3
	EL 1	1.00BF53.8 Elec	116.5	473.5	534.3
	EL 1	1.00B49.0 Elec	106.4	432.4	488.0
	EL 1	1.00B47.0 Elec	102.2	415.2	468.6

6.4.2 Incandescent Reflector Lamps

Because an IRL does not require a ballast to operate, the rate of energy usage is simply the rated power of the lamp. Table 6.4.10 presents power ratings for all of the IRL designs. DOE calculated the annual energy consumption based on the U.S. weighted-average annual operating hours for IRLs in the residential and commercial sectors as 763 hours and 4,532 hours, respectively. As mentioned previously, DOE did not analyze IRLs in the industrial sector because of their low market share in that sector. Appendix 6A of this TSD lists the annual energy consumption of those IRL designs used in the lighting controls scenarios.

Table 6.4.10 Annual Energy Consumption for IRLs, Commercial and Residential Sectors

Technology Option	Lamp Power Rating	Annual Energy Consumption	
		Commercial	Residential
	<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline : Improved Halogen	60	271.9	45.8
EL 1 Rep. Unit 1: HIR	55	249.2	42.0
EL 1 Rep. Unit 2: Improved HIR	55	249.2	42.0

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CHAPTER 7. PRODUCT PRICE DETERMINATION

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CHAPTER 7. PRODUCT PRICE DETERMINATION

7.1 INTRODUCTION

This chapter describes the methodology the U.S. Department of Energy (DOE) followed in developing end-user prices for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs) being proposed in this rulemaking. It also provides the results for the lamp end-user prices.

In energy conservation standards rulemakings, DOE often develops cost-efficiency relationships in the engineering analysis (chapter 5 of this notice of proposed rulemaking [NOPR] technical support document [TSD]). Then, DOE applies markups to derive end-user prices. For this rulemaking, DOE derived efficacy levels (ELs) in the engineering analysis and prices in this chapter of this NOPR TSD. The product price determination develops end-user prices directly because reverse-engineering a lamp is impractical, as the lamps are not easily disassembled. By combining the results of the engineering analysis and the product price determination, DOE derived typical inputs for use in the life-cycle cost (LCC; chapter 8 of this NOPR TSD) analysis and the national impact analysis (NIA; chapter 12 of this NOPR TSD).

Because DOE recognizes that consumers may be required to purchase a new ballast to accommodate higher efficacy GSFLs and/or choose to replace their ballast to obtain higher energy savings, DOE also developed prices for ballasts. Appendix 7A of this NOPR TSD describes the methodology used to derive the end-user prices for the ballasts that are presented in the engineering analysis.

7.2 METHODOLOGY

End-user price refers to the product price a consumer pays before tax and installation. In its review of publicly available prices for GSFLs and IRLs, DOE observed a range of end-user prices paid for a lamp, depending on the distribution channel through which the lamp is purchased. Based on feedback from manufacturer interviews, GSFL and IRL manufacturers usually sell through a distribution chain that may involve dealers or retailers; distributors or wholesalers; contractors; state, city, or local governments; and original equipment manufacturers (OEMs). Of the possible distribution chains, DOE identified three main channels (state procurement, large distributors including do-it-yourself stores, and Internet retailers). Using these main channels, DOE developed three different end-user prices (low, medium, and high) as representative of a range of publicly available prices. DOE then developed an average weighted end-user price using estimated percentage of shipments that go through each distribution channel obtained in interviews with manufacturers.

7.2.1 Discount Determination

DOE first collected manufacturer suggested price lists (hereafter referred to as “blue books”) for covered GSFLs and IRLs. Blue book prices refer to suggested retail prices issued by manufacturers and are usually specified for bulk quantity purchases. Starting with a consistent set of aggregated blue book prices, DOE calculated an average discount ratio based on the

corresponding lamp prices offered in state procurement contracts and by Internet retailers.^a DOE found that the discounts did not vary with wattage or efficacy, and therefore applied a single discount for all GSFLs and a single discount for IRLs to estimate end-user prices.

State procurement contracts typically offered the greatest discounts off blue book prices: approximately 84 percent off the blue book for GSFLs and about 73 percent off the blue book for IRLs. These contract prices represent large purchases and therefore reflect steep discounts. Therefore state procurement contract pricing constitutes the high discount and was used to develop the low end-user prices. Prices were the highest at Internet retailers because consumers typically purchase from Internet retailers in small volumes. Discounts based on Internet retailers were approximately 60 percent off the blue book for GSFLs and about 42 percent off the blue book for IRLs. Therefore, Internet retailer pricing constitutes the low discount and was used to develop the high end-user prices.

DOE was unable to find an adequate amount of pricing information from large distributors, such as do-it-yourself stores, to empirically determine a discount factor. Distributor prices are generally not publicly available and the price quotes that could be obtained from distributors reflected regional discounts. DOE visited several large distributors, including Home Depot, Lowe's, Target, and Walmart, but found very few covered products that were compliant with the standards adopted in the 2009 Lamps Rule that require compliance in July 2012 (hereafter the "July 2012 standards"). However, manufacturer feedback and DOE research indicated that the large distributor channel represents the medium price relative to the state procurement and Internet prices. Therefore, using an average of the state procurement and Internet discounts, DOE developed a medium discount of approximately 72 percent off the blue book for GSFLs and about 58 percent off the blue book for IRLs. These discounts were used to develop the medium end-user prices.

DOE then developed an end-user price that was weighted by distribution channel. Based on manufacturer feedback in interviews DOE determined an aggregated percentage of shipments that go through each distribution channel for GSFLs and IRLs. The large distributors and DIY stores channel was estimated at 85 percent, the state procurement channel at 10 percent, and the Internet retail channel at 5 percent. DOE then applied these percentages respectively to the medium price determined for large distributor and DIY stores, the low price determined for state procurement contracts, and the high price determined for Internet retailers. The sum of these weighted prices was used as the average consumer price for GSFLs and IRLs in the main LCC analysis and NIA. DOE utilized the low prices and high prices in a sensitivity analysis within the LCC analysis. See chapter 8 and appendix 8B of this NOPR TSD for further information on the results of the LCC and its sensitivities, and chapter 12 for the results of the NIA.

7.2.2 End-User Price Determination

In chapter 5 of this NOPR TSD, DOE identified representative lamps for each EL analyzed in the GSFL and IRL product classes. DOE applied the discounts developed in section

^a To calculate discounts for state procurement contracts and internet retailers, DOE analyzed lamps that had more than one state procurement price or Internet retail price.

7.2.1 to the aggregated blue book values of each representative lamp to obtain a low, medium, and high end-user price. For the representative lamps for which blue book prices were unavailable, DOE extrapolated pricing from similar lamps whose blue book prices were available. This was done by using the blue book prices of equivalent lamps from an alternative manufacturer and by developing price ratios based on wattage and/or technology, as appropriate.

For the 8-foot recessed double contact (RDC) high output (HO), T5 miniature bipin (MiniBP) standard output (SO), and T5 MiniBP high output (HO) product classes, DOE modeled baseline lamps at the existing standard because there were no commercially available lamps at this efficacy level. In order to determine prices for the modeled lamps, DOE developed a relationship between efficacy and blue book values using full wattage commercially available lamps at higher efficacies for these product classes to determine the price for the lamp modeled at the baseline level. For the T5 HO product class, DOE could not develop a relationship between efficacy and blue book values of full wattage lamps because only one full wattage lamp was commercially available. Thus, DOE used the relationship between efficacy and blue book values for the higher efficacy T5 SO products to determine an aggregated blue book value for the modeled T5 HO baseline lamp.

After generating end-user prices, DOE added sales tax and installation costs, where appropriate, to derive the total, installed end-user cost for the LCC analysis (chapter 8 of this NOPR TSD).

7.2.3 Exception Relief for 700 Series T8 GSFLs

At the time of this analysis, Philips Lighting Company (Philips), GE Lighting (GE), OSRAM SYLVANIA, Inc. (OSI), Ushio America, Halco Lighting Technologies, Premium Quality Lighting, Inc., Tailored Lighting, Inc., Litetronics International, Inc., Satco Products, Inc., DLU Lighting USA, Westinghouse Lighting Corporation, Ascent Battery Supply, L.L.C., EiKO, Ltd., Topaz Lighting Corporation, Technical Consumer Products (TCP), and Feit have been granted waivers exempting their 700 series T8 lamps from the July 2012 standards for a period of two years. This group includes the three manufacturers that hold the majority of the domestic market share of GSFLs (GE, OSI, and Philips). The waiver was granted per the Requests for Adjustments provision (also known as “exception relief”), which allows a manufacturer to submit a hardship waiver to DOE’s Office of Hearings and Appeals (OHA).

In this case, the exception relief focused on the impact of standards on the supply and demand of rare earth phosphors. Rare earth phosphors are a key technology in increasing the efficacy of fluorescent lamps. Specifically, the use of terbium, europium, and yttrium allows a lamp to emit light at the wavelengths to which human eyes are most sensitive. The exception relief was sought and granted on the basis that due to the global supply restriction of rare earth phosphors and rising world demand for these phosphors, manufacturers would be unable to attain the necessary amount to produce standards-compliant lamps.¹ See appendix 11B of this NOPR TSD for an assessment of rare earth price volatility.

As noted previously, DOE used the latest lamp prices available at the time of this analysis, which are reflective of a market in which most companies are able to manufacture and/or sell non-compliant 700 series T8 lamps. Based on the reasoning by which the exception

relief was granted, the requirement for more rare earth phosphors to produce standards-compliant lamps (*i.e.*, 800 series for most product classes) and the subsequent rising prices of these phosphors may drive lamp prices higher than at the time of this analysis (*i.e.*, with the exception relief in place). However, due to the exception relief, there is no historical pricing data to analyze for a market in which 700 series T8 non-compliant lamps were not available. Therefore, DOE was unable to determine the exact impact on lamp prices as a result of an increased demand for rare earth phosphors due to existing GSFL standards. However, DOE has conducted sensitivity analyses that evaluate the potential impacts of changes in rare earth prices on lamp prices and subsequently, cost to the consumer.

DOE derived a high rare earth phosphor price scenario using historical phosphor price data and determined the impacts of these scenarios on LCC savings and NIA results. See appendix 11B for a description of the rare earth phosphor impact scenario assessed in the NIA and chapter 12 of this NOPR TSD for results of this sensitivity for the NIA. See appendix 8B of this NOPR TSD for results of this sensitivity for the LCC. DOE also determined the maximum possible increase in rare earth phosphor prices that would maintain positive LCC savings for consumers at each CSL. See appendix 7B of this NOPR TSD for results of this analysis.

7.3 RESULTS

Sections 7.3.1 and 7.3.2 below summarize the low, medium, high end-user prices, and weighted end-user prices for GSFLs and IRLs. Prices for ballasts are presented in appendix 7A of this NOPR TSD.

7.3.1 End-User Prices for General Service Fluorescent Lamps

The following tables present the end-user prices for GSFLs. The prices presented do not include sales tax.

Table 7.3.1 End-User Prices for 4-Foot Medium Bipin GSFLs

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i>	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price <i>2012\$</i>	Medium Price <i>2012\$</i>	High Price <i>2012\$</i>	Weighted Price <i>2012\$</i>
Baseline	32.5	89.2	2,900	2,725	83	24,000	\$2.92	\$5.10	\$7.29	\$4.99
EL 1	32.5	90.0	2,925	2,770	85	21,000	\$3.22	\$5.63	\$8.04	\$5.51
EL 2	26.6	93.0	2,475	2,350	85	24,000	\$6.42	\$11.24	\$16.06	\$11.00
EL 2	32.5	95.4	3,100	2,945	85	24,000	\$5.57	\$9.75	\$13.92	\$9.54
EL 2	28.4	96.0	2,725	2,590	85	24,000	\$4.80	\$8.41	\$12.01	\$8.23

Table 7.3.2 End-User Prices for 4-foot T5 Miniature Bipin (MiniBP) SO GSFLs

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i> (at 35 °C)	Lamp Efficacy <i>lm/W</i> (at 25 °C)	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price 2012\$	Medium Price 2012\$	High Price 2012\$	Weighted Price 2012\$
Baseline	27.8	94.6	86	2,630	2,446	85	30,000	\$2.40	\$4.19	\$5.99	\$4.10
EL 1	27.8	104.3	93.5	2,900	2,697	85	30,000	\$3.47	\$6.07	\$8.67	\$5.94
EL 2	27.8	109.7	98.2	3,050	2,898	85	30,000	\$4.12	\$7.22	\$10.31	\$7.06
EL 2	26.0	111.5	100.0	2,900	2,775	85	30,000	\$5.00	\$8.75	\$12.50	\$8.56
EL 2	25.0	116.0	104.0	2,900	2,750	85	35,000	\$5.76	\$10.09	\$14.41	\$9.87

Table 7.3.3 End-User Prices for 4-foot T5 MiniBP HO GSFLs

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i> (at 35 °C)	Lamp Efficacy <i>lm/W</i> (at 25 °C)	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price 2012\$	Medium Price 2012\$	High Price 2012\$	Weighted Price 2012\$
Baseline	53.8	83.6	76	4,498	4,273	85	25,000	\$3.30	\$5.78	\$8.26	\$5.66
EL 1	53.8	92.9	82.7	5,000	4,750	85	25,000	\$5.54	\$9.69	\$13.84	\$9.48
EL 1	49.0	102.0	90.8	5,000	4,600	85	35,000	\$7.18	\$12.57	\$17.95	\$12.30
EL 1	47.0	102.1	91.9	4,800	4,410	84	30,000	\$7.99	\$13.99	\$19.98	\$13.69

Table 7.3.4 End-User Prices for 8-foot Single Pin (SP) Slimline GSFLs

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i>	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price 2012\$	Medium Price 2012\$	High Price 2012\$	Weighted Price 2012\$
Baseline	60.1	96.5	5,800	5,220	80	24,000	\$6.12	\$10.71	\$15.30	\$10.48
EL 1	60.1	98.2	5,900	5,490	85	24,000	\$6.85	\$12.00	\$17.14	\$11.74
EL 2	60.1	99.0	5,950	5,650	85	24,000	\$8.28	\$14.49	\$20.70	\$14.18
EL 2	54.0	105.6	5,700	5,415	85	24,000	\$10.78	\$18.86	\$26.94	\$18.46

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i>	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price <i>2012\$</i>	Medium Price <i>2012\$</i>	High Price <i>2012\$</i>	Weighted Price <i>2012\$</i>
EL 2	50.0	108.0	5,400	5,075	85	24,000	\$12.83	\$22.45	\$32.08	\$21.97

Table 7.3.5 End-User Prices for 8-foot Recessed Double Contact (RDC) HO GSFLs

EL	ANSI Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i>	Initial Lumen Output <i>lm</i>	Mean Lumen Output <i>lm</i>	CRI	Rated Life <i>hrs</i>	Low Price <i>2012\$</i>	Medium Price <i>2012\$</i>	High Price <i>2012\$</i>	Weighted Price <i>2012\$</i>
Baseline	84.0	92.0	7,728	7,342	78	18,000	\$5.04	\$8.82	\$12.60	\$8.63
EL 1	84.0	95.2	8,000	7,600	78	18,000	\$7.70	\$13.48	\$19.25	\$13.19
EL 2	84.0	97.6	8,200	7,800	85	18,000	\$9.70	\$16.97	\$24.24	\$16.61

7.3.2 End-User Prices for Incandescent Reflector Lamps

The following table presents the end-user prices for IRLs. The prices presented do not include sales tax.

Table 7.3.6 End-User Prices for IRLs

EL	Lamp Shape	Lamp Wattage <i>W</i>	Lamp Efficacy <i>lm/W</i>	Initial Lumen Output <i>lm</i>	Rated Life <i>hrs</i>	Low Price <i>2012\$</i>	Medium Price <i>2012\$</i>	High Price <i>2012\$</i>	Weighted Price <i>2012\$</i>
Baseline	PAR38	60	17.8	1,070	1,500	\$5.77	\$8.98	\$12.39	\$8.83
EL 1	PAR38	55	18.5*	980	2,500	\$7.34	\$11.41	\$15.76	\$11.22
EL 1	PAR38	55	18.5*	1,120	4,200	\$8.49	\$13.20	\$18.24	\$12.98

*Lamp efficacy values are based on certification data.

REFERENCES

¹ *Philips Lighting Company, et al.* OHA Case Nos. EXC-12-0001, EXC-12-0002, EXC-12-0003 (2012). Accessible here: <http://energy.gov/sites/prod/files/oha/EE/EXC-12-0001thru03.pdf>.

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSES

8.1 INTRODUCTION

This chapter describes the analysis the U.S. Department of Energy (DOE) conducts to evaluate the economic impacts on individual consumers of potential energy conservation standards for general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). New standards usually decrease operating costs and increase purchase costs for consumers. This chapter describes the three metrics used in this analysis to determine the impact of standards on individual consumers:

Life-cycle cost (LCC) is the total (discounted) consumer cost over the analysis period including purchase price, operating costs (including energy expenditures), and installation costs.

Payback period (PBP) is the number of years it takes a consumer to recover the generally higher purchase price of a more energy-efficient product through the operating cost savings of using the more energy-efficient product. DOE calculates the PBP by dividing the change in first cost by the change in operating costs in the first year.

Rebuttable presumption PBP is a special case in which the PBP is calculated based on laboratory conditions, specifically DOE test procedure inputs. DOE calculates the aforementioned LCC and PBP using a range of inputs, which are designed to reflect actual conditions.

Sections 8.2 and 8.3 discuss inputs to the LCC and PBP, respectively. Section 8.4 discusses the different purchasing events DOE analyzes, which affect consumer economics. Section 8.5 presents the results for the LCC and PBP. Key variables and calculations are presented for each metric. DOE performs the calculations discussed here using a Microsoft Excel[®] spreadsheet developed for this rulemaking. DOE invites stakeholders to download and examine the spreadsheet, which is available on regulations.gov, docket number EERE-2011-BT-STD-0006, at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006. Appendix 8A presents details and instructions for using the spreadsheet. Appendix 8B presents sensitivity results as well as results of the Monte Carlo model. Appendix 8C presents detailed sources for the residential sector discount rate computation. Appendix 8D presents the impact of “hot shock” on the LCC savings of IRLs.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analyses

Recognizing that several inputs to the LCC and PBP analyses are either variable or uncertain, DOE incorporates Monte Carlo simulation and probability distributions into its LCC and PBP model. Section 8.5 includes the percentage of consumers who would experience a net benefit or net loss by purchasing a standard case design instead of a base case design using Monte Carlo simulation. Appendix 8B contains a detailed set of LCC and PBP results using Monte Carlo simulation. DOE incorporates both Monte Carlo simulation and probability

distributions by using Microsoft Excel spreadsheets combined with Crystal Ball[®], a commercially available add-in program.

The relationship between increasing total installed cost and increasing efficacy is the most significant factor that influences the LCC and PBP results. However, other factors related to the characteristics of the consumer using the products also affect the results. Factors such as energy prices, sales tax, and energy usage can vary based on the geographic region, sector, and building type in which a consumer uses the lamps. DOE accounts for this variability by using the Monte Carlo simulation and separate sensitivity runs.

For the LCC and PBP analyses, DOE considers variability in the discount rate. DOE also models variability in operating hours by end-user sector, geographic region, lamp type, and building type. By including a distribution of building types, DOE can perform the LCC and PBP calculations and account for the variability in operating hours, electricity price, and sales tax among a variety of buildings. DOE used the Energy Information Administration's (EIA's) 2009 Residential Energy Consumption Survey (RECS),¹ 2003 Commercial Buildings Energy Consumption Survey (CBECS),² 2006 Manufacturing Energy Consumption Survey (MECS),³ and the 2010 U.S. Lighting Market Characterization (LMC)⁴ to develop probabilities of lamp types in buildings and the operating hour characteristics of the lamps in those buildings. The LCC and PBP spreadsheets present the results of the analysis as average values, relative to the baseline conditions. Appendix 8B presents more information on the distribution of results from the LCC and PBP analyses, including the average and median PBP values.

In the LCC and PBP analyses, DOE considers multiple pathways to energy savings. Generally, when moving up in lamp efficacy, consumers choose whether to stay at the same rated lamp wattage and have more light output, or move to a reduced wattage and have the same or roughly equivalent light output as the baseline lamp or lamp-and-ballast system. While consumers clearly would have other choices in addition to those presented in the LCC, DOE did not consider lamps or lamp-and-ballast systems that increase energy consumption in the LCC. The shipments analysis in chapter 11 of this notice of proposed rulemaking (NOPR) technical support document (TSD) addresses higher-energy systems, along with other consumer behavior, such as choosing another lamp technology (*e.g.*, LEDs).

For GSFLs, DOE considers various scenarios that prompt consumers to buy a lamp or lamp-and-ballast system because the "event" that prompts the purchase of a new lamp (*e.g.*, a lamp failure or a ballast failure) can influence the cost-effectiveness of the consumer purchase decision. For example, a consumer may or may not need to purchase a new ballast when purchasing a new lamp. Therefore, DOE based the LCC and PBP analyses around "lamp purchasing events." For GSFLs, DOE analyzed lamp failure, ballast failure, and new construction/renovation scenarios. For IRLs, where no ballast is involved, DOE simply analyzed lamp failure or new construction/renovation scenarios. Section 8.4 discusses the lamp purchasing events in more detail. The LCC and PBP analyses' spreadsheet reports results by purchasing event.

The time period used for the LCC and PBP analyses in this rulemaking is the service life of the baseline lamp for each analysis. By using this analysis period, LCC results are more easily compared and contrasted for different efficacy levels (ELs). However, to account for any

remaining lamp life at the end of the analysis period in a manner consistent with the Federal Energy Management Program’s Life-Cycle Costing Manual,⁵ DOE designates a discounted “residual value” for lamps or ballasts that have remaining value. For example, if a more-efficacious lamp expires before the end of the analysis period, DOE assumed that the consumer replaces the lamp during the analysis period and credits the unused lamp life of this replaced lamp back as a residual value at the end of the analysis period.

DOE conducted the LCC and PBP analyses on the baseline lamps from the representative product classes identified in chapter 5 of this NOPR TSD. Table 8.1.1 shows the set of five representative GSFL product classes and the one representative IRL product class that DOE evaluated in this analysis.

Table 8.1.1 Representative Product Classes Analyzed in the LCC and PBP Analyses

General Service Fluorescent Lamps
4-Foot Medium Bipin, CCT* $\leq$ 4,500 K
8-Foot Single Pin Slimline, CCT $\leq$ 4,500 K
8-Foot Recessed Double Contact High Output (HO), CCT $\leq$ 4,500 K
4-Foot T5 Miniature Bipin Standard Output (SO), CCT $\leq$ 4,500 K
4-Foot T5 Miniature Bipin HO, CCT $\leq$ 4,500 K
Incandescent Reflector Lamps
Standard Spectrum, Voltage < 125 V, Diameter > 2.5 Inches

*Correlated color temperature (CCT)

8.1.2 Overview of LCC and PBP Inputs

As mentioned earlier, the LCC represents the total consumer expense over the analysis period, including purchase expenses, operating costs (including energy expenditures), and installation costs, if applicable. DOE discounts future operating costs to the time of purchase and sums them over the analysis period. Due to the large variance of lamp lifetimes, for this rulemaking, DOE based the analysis period on the life of the baseline lamp used in each analysis. The LCC calculation credits back the residual value of a lamp, or lamp-and-ballast system, if it has any operating life remaining at the end of the analysis period. The residual value is the discounted total installed cost of a lamp, or lamp-and-ballast system, multiplied by the percentage of the remaining life past the analysis period. The PBP represents the number of years it takes consumers to recover the purchase price of more-efficacious products through lower operating costs. DOE calculates the PBP by dividing the change in first cost by the change in operating costs in the first year.

DOE categorizes inputs to the LCC and PBP analysis as follows: (1) inputs for establishing the purchase expense, otherwise known as the total installed cost; and (2) inputs for calculating the expenses incurred during the operation of the lamp, otherwise known as the operating cost. In addition, DOE uses inputs to the LCC to calculate a residual value for any remaining product lifetime beyond the analysis period and replacement costs for those lamps whose service life is less than the analysis period.

The primary inputs for establishing the LCC and PBP are:

End-User Product Price: As discussed in chapter 7 of this NOPR TSD, DOE started with manufacturer suggested price lists (“blue-books”), and applied discounts to develop low, medium, and high prices for all lamp types. DOE then developed a weighted average end-user price based on the percentage of shipments that go through each distribution channel. The end-user product prices represent the consumer price before tax and installation.

Sales Tax: DOE then applied sales tax to convert the end-user product price to a final product price including sales tax.

Installation Cost: This input represents the cost to commercial or industrial consumers of installing the lamps or lamp-and-ballast systems. (In the residential sector, there is only an installation cost for lamp systems when a new ballast is being installed.) The installation cost represents all costs required to install the lamp or lamp-and-ballast system, but does not include the end-user product price. The installation cost includes labor and overhead. Thus, the total installed cost equals the end-user product price including sales tax plus the installation cost.

Disposal Cost: After a GSFL reaches the end of its life, some consumers pay to recycle the lamp. The disposal cost represents the cost of recycling a GSFL and is only applicable to those consumers in the commercial and industrial sectors.

The primary inputs for calculating the operating cost include the following:

Annual Operating Hours: The annual operating hours are the hours that a lamp is estimated to be in use during one year. The energy use characterization (chapter 6 of this NOPR TSD) details how DOE determined the lamp operating hours as a function of end-user sector, geographic region, lamp type, and building type.

Power Rating: The power rating is the site energy usage rate associated with operating the lamp or lamp-and-ballast system. The energy use characterization (chapter 6 of this NOPR TSD) details how DOE determined the power ratings for the lamps and lamp-and-ballast systems considered in the analyses.

Electricity Prices: DOE uses the average price per kilowatt-hour (\$/kWh) paid by consumers. For the Monte Carlo distribution, DOE determined electricity prices for GSFLs and IRLs using average residential, commercial, and industrial values for 9 regions and 4 large states. For the sample calculation, DOE calculated a weighted national average using the probability of a GSFL or IRL in each region or large state. DOE developed all electricity price inputs using 2011 EIA data scaled to 2012.

Electricity Price Trends: DOE used the EIA’s *Annual Energy Outlook 2013 (AEO 2013)* to forecast electricity prices.⁶ For the results presented in this chapter, DOE used the *AEO 2013* reference case to forecast future electricity prices.

Lifetime: Lifetime is the total hours in operation until the consumer retires the lamp or components of a lamp system from service.

Discount Rate: The discount rate is the rate at which DOE discounts future expenditures to establish their present value.

Analysis Period: Analysis period is the time span over which DOE calculates the LCC.

DOE also accounted for the effects of lighting controls in the LCC analysis as presented in appendix 8B. See appendix 6A of this NOPR TSD for further discussion on lighting controls.

The residual value calculation also uses all of the installed cost inputs, as well as several operating cost inputs.

Figure 8.1.1 depicts the relationships between the installed cost, operating cost, and residual value inputs for the calculation of the LCC and PBP. In this figure, the rectangular boxes indicate the inputs, the parallelograms indicate intermediate calculated values, and the diamond boxes indicate the analysis outputs (the LCC and PBP).

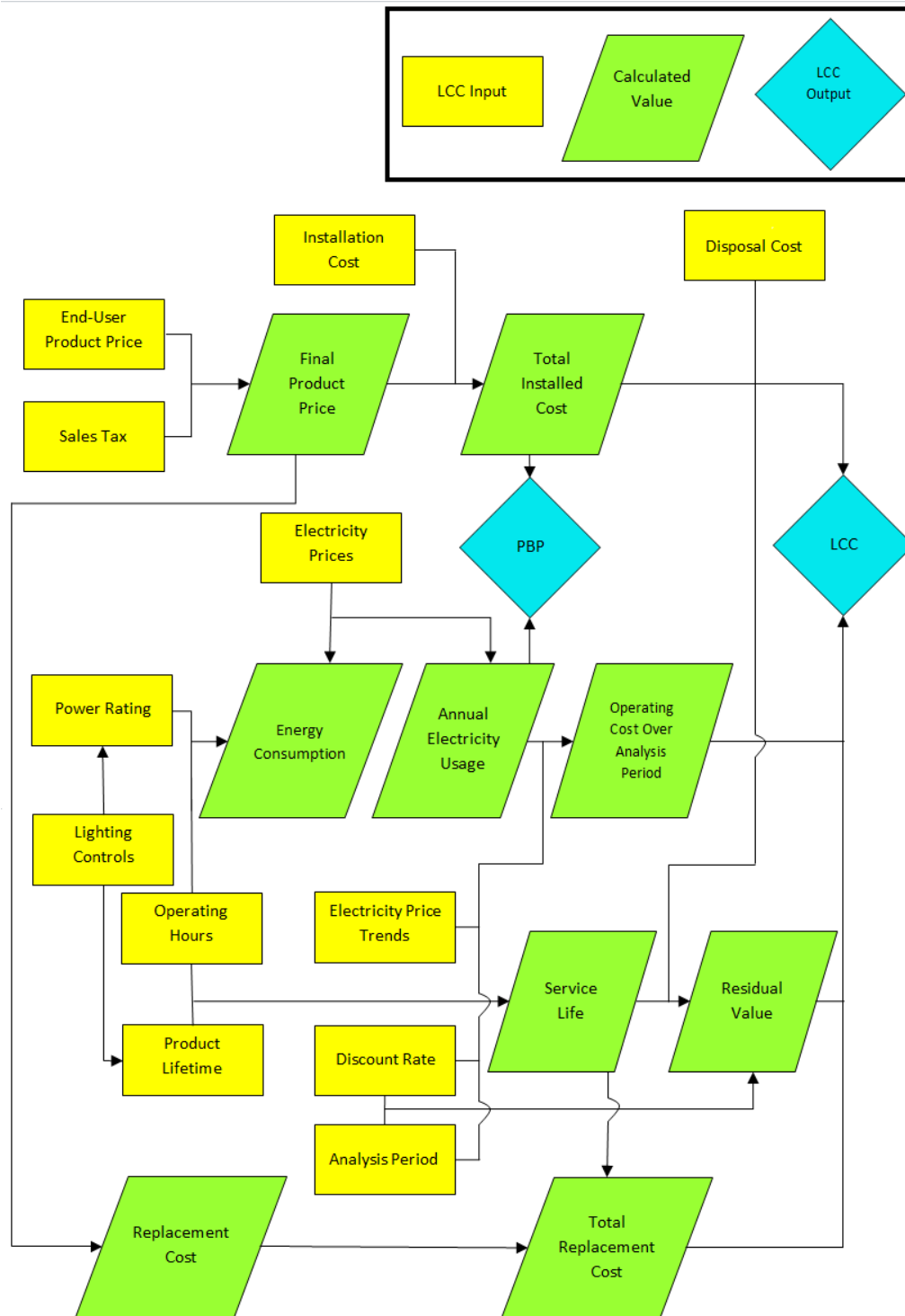


Figure 8.1.1 Flow Diagram of Inputs for the Determination of LCC and PBP

Table 8.1.2 summarizes the input values that DOE used to calculate the LCC and PBP for GSFLs and IRLs. DOE characterizes all of the total installed cost inputs with single-point values, but characterizes several of the operating cost inputs with probability distributions that capture the input's uncertainty and/or variability in the Monte Carlo analysis. Table 8.1.2 also lists the chapters of this NOPR TSD that detail the inputs.

Table 8.1.2 Summary Information of Inputs for the Life-Cycle Cost and Payback Period Analyses

Factor	Weighted Average Value	TSD Reference Section
Total Installed Cost Primary Inputs		
End-User Product Price	Varies with lamp and ballast	Chapter 7, 11
Sales Tax	Varies by census region and lamp type	Chapter 8
Installation Cost	Varies by product installed and sector	Chapter 8
Operating Cost Primary Inputs		
Annual Operating Hours	Vary by lamp type, sector, and building type	Chapter 6
Power Rating	Varies with lamp type, and lamp or lamp-and-ballast system	Chapter 5, 6
Electricity Prices	Vary by lamp type, sector, and census region	Chapter 8
Electricity Price Trends	Vary with price forecast scenario	Chapter 8
Discount Rate	Varies with sector	Chapter 8
Analysis Period	Varies with baseline lamp and annual operating hours	Chapter 8
Replacement Cost and Residual Value Primary Inputs		
Total Installed Cost	Varies with lamp or lamp-and-ballast, census region, product installed, and sector	Chapters 7, 8
Lifetime	Varies with lamp and system	Chapters 5, 8
Disposal Cost	Varies by lamp type and sector	Chapter 8
Discount Rate	Varies with sector	Chapter 8
Analysis Period	Varies with baseline lamp and annual operating hours	Chapter 8

8.2 LIFE-CYCLE COST INPUTS

8.2.1 Definition

LCC is the total consumer cost over the life of a product, including total installed costs, operating costs, replacement costs, and residual value. DOE discounts future operating costs and replacement costs to the analysis start year (2017) and sums them over the analysis period. DOE credits residual value (if any) back to the LCC, if the operating life of the standards case technology exceeds that of the analysis period. The following equation defines the LCC:

$$LCC = IC + \sum_{t=1}^N \left(\frac{OC_t + RC_t}{(1+r)^t} + \frac{DC}{(1+r)^t} \right) - \frac{RV}{(1+r)^N} \quad \text{Eq. 8.1}$$

Where:

LCC	=	life-cycle cost (\$),
IC	=	total installed cost (\$),
N	=	analysis period,
$\sum$	=	sum over the analysis period, from year 1 to year N,
OC	=	operating cost (\$),
RC	=	replacement cost (\$),
r	=	discount rate,
t	=	year for which operating cost, replacement cost, or disposal cost is determined,
DC	=	disposal cost of the lamp, and
RV	=	residual value for an analysis period N .

DOE expresses all the costs in its LCC and PBP analyses in 2012 dollars.

8.2.2 Total Installed Cost Inputs

The total installed cost to the consumer is defined by the following equation:

$$IC = FPP + INST \quad \text{Eq. 8.2}$$

Where:

IC	=	installed cost
FPP	=	final product price (<i>i.e.</i> , consumer price for the product only, including sales tax) (\$), and
$INST$	=	installation cost or the consumer price to install products (<i>i.e.</i> , the cost for labor and materials) (\$).

In the product price determination (see chapter 7 of this NOPR TSD), DOE developed end-user product prices. DOE added sales taxes to derive final product prices. DOE then applied installation costs, where necessary, to derive the total installed costs for use in the LCC. Table 8.2.1 shows the inputs to determine total installed costs.

Table 8.2.1 Inputs for Total Installed Costs

End-User Product Price (\$)
Sales Tax (\$)
Installation Cost (\$)

The end-user product price is the average purchase price a consumer pays before sales tax for lamps or lamp-and-ballast systems. The sales tax represents state and local sales taxes applied

to the end-user product price. It is a multiplicative factor that increases the end-user product price. Installation cost is the cost to the consumer of installing the lamps or lamp-and-ballast systems, and only applies in the commercial and industrial sectors (and in the residential sector if a ballast replacement is required). The installation cost represents all costs required to install the lamp or lamp-and-ballast system (including labor and overhead) but does not include the final product price. The total installed cost equals the final product price plus the installation cost. DOE calculates the total installed cost for the lamps analyzed based on the following equation:

$$\begin{aligned} IC &= FPP + INST \\ &= PRICE \times MU_{TAX} + INST \end{aligned} \quad \text{Eq. 8.3}$$

Where:

<i>IC</i>	=	total installed cost,
<i>FPP</i>	=	final product price,
<i>INST</i>	=	installation cost,
<i>PRICE</i>	=	end-user product price, and
<i>MU_{TAX}</i>	=	sales tax mark up

The following sections discuss product price, sales tax, and installation cost in more detail. Chapter 7 of this NOPR TSD provides additional information on the end-user product price

8.2.2.1 Product Price

In its Notice of Data Availability (NODA) published on February 22, 2011 (76 FR 9696), DOE stated that it may consider improving the regulatory analysis by addressing product price trends. Consistent with the NODA, DOE examined historical Producer Price Indices (PPI) for “electric lamp bulb and part manufacturing” from the Bureau of Labor Statistics, as well as other price forecasting indices to determine the best way to analyze price trends for GSFLs, IRLs, and ballasts. After analyzing available data, DOE concluded that the real prices of these products have a different long-term trend than prices in the economy as a whole. Chapter 11 of this NOPR TSD discusses how DOE forecasted product prices throughout the analysis period for GSFLs, IRLs, and ballasts.

In addition, DOE accounts for the variability of rare earth oxide prices in the product price. The reference assumption for rare earth oxide prices is that they remain constant at the September 2013 level. Rare earth prices rose rapidly in 2010 to a peak in 2011 and dropped almost monotonically to less than half their peak since then. The future trajectory of rare earth oxide prices is highly uncertain. Therefore, DOE developed alternative scenarios for volatile prices reflecting the 2011 peak price and the 2006 – 2009 baseline average price. See appendix 11B of this NOPR TSD for a discussion of how DOE developed the estimates for volatile rare earth phosphor prices. Appendix 8B of this NOPR TSD contains LCC results based on these estimates.

8.2.2.2 Sales Tax

The sales tax represents state and local sales taxes applied to the end-user product price. It is a multiplicative factor that increases the end-user product price. DOE obtained information on state and local sales tax from the Sales Tax Clearinghouse.⁷ Table 8.2.2 shows the rates; these data represent weighted averages that include county and city rates. DOE then calculated population-weighted average tax values for each census division and four large states.⁸ DOE also calculated a national weighted average sales tax for each sector based on the probability of a GSFL or IRL within each division or large state. See chapter 6 of this NOPR TSD for further discussion of the how DOE calculated this probability.

Table 8.2.2 State and Local Sales Tax Rates

State	Combined State and Local Tax Rate (%)	State	Combined State and Local Tax Rate (%)	State	Combined State and Local Tax Rate (%)
Alabama	8.55	Kentucky	6.00	North Dakota	5.95
Alaska	1.35	Louisiana	8.75	Ohio	7.05
Arizona	7.15	Maine	5.00	Oklahoma	8.40
Arkansas	8.90	Maryland	6.00	Oregon	0.00
California	8.45	Massachusetts	6.25	Pennsylvania	6.40
Colorado	6.10	Michigan	6.00	Rhode Island	7.00
Connecticut	6.35	Minnesota	7.20	South Carolina	7.20
Delaware	0.00	Mississippi	7.00	South Dakota	5.40
Dist. Of Columbia	6.00	Missouri	7.45	Tennessee	9.45
Florida	6.65	Montana	0.00	Texas	7.95
Georgia	7.10	Nebraska	6.00	Utah	6.70
Hawaii	4.40	Nevada	7.85	Vermont	6.05
Idaho	6.05	New Hampshire	0.00	Virginia	5.60
Illinois	8.05	New Jersey	6.95	Washington	8.90
Indiana	7.00	New Mexico	6.60	West Virginia	6.05
Iowa	6.85	New York	8.40	Wisconsin	5.45
Kansas	7.90	North Carolina	6.90	Wyoming	5.50

Table 8.2.3 shows the distribution of sales tax rates DOE developed for the LCC and PBP analyses. The distribution ranges from a minimum of 5.30 percent to a maximum of 8.67 percent with sector-weighted average values of 7.12-7.17 percent.

Table 8.2.3 Regional Average Tax Rates

Census Division or Large State Name	Census Division Weighted Sales Tax (%)
New England	5.64
Mid Atlantic	6.63
East North Central	6.90
West North Central	7.10
South Atlantic	6.40
East South Central	8.01
West South Central	8.67
Mountain	6.45
Pacific	5.30
New York State	8.40
California	8.45
Texas	7.95
Florida	6.65
Residential Sector-Weighted Average	7.12
Commercial Sector-Weighted Average	7.13
Industrial Sector-Weighted Average	7.17

8.2.2.3 Installation Costs

DOE applied installation costs to individual lamps, as well as lamp-and-ballast systems, installed in the commercial and industrial sectors. DOE assumed that in the residential sector, the homeowner replaces individual lamps; thus, DOE applied installation costs only to lamp-and-ballast systems in the residential sector.

On November 14, 2011, DOE issued a final rule establishing energy conservation standards for ballasts (hereafter referred to as “the 2011 Ballast Rule”). 76 FR 70548 (Nov. 14, 2011); 10 CFR 430.32(m)(8). For GSFLs, DOE obtained estimates of the prevalence of group versus spot relamping from the 2011 Ballast Rule. In spot relamping, consumers replace failed lamps on a one-by-one basis. In group relamping, consumers replace all the lamps in a fixture or area at a predetermined time. DOE obtained the time it takes to complete a spot and group relamping or “relamping time” from the 2011 Ballast Rule. DOE then weighed the relamping time by the percent occurrence of spot versus group relamping to derive weighted average relamping times. According to the 2011 Ballast Rule, group relamping occurs, on average, 25 percent of the time for 4-foot systems versus spot relamping 75 percent of the time, 37 percent of the time for 8-foot single pin (SP) slimline systems versus spot relamping 63 percent of the time, and 31 percent of the time for 8-foot recessed double contact (RDC) HO systems versus spot relamping 69 percent of the time.⁹ DOE used these percentages to calculate an average installation time in the commercial and industrial sectors. For entire lamp-and-ballast system installations, DOE used the times shown in the “Time to Install Lamps and Ballasts” column in Table 8.2.4 from the 2011 Ballast Rule.

To account for installation costs for IRLs, DOE used relamping time estimates from the *RS Means Electrical Cost Data, 2007 (RS Means)*.¹⁰ Table 8.2.4 lists average labor times to install a lamp (for IRLs and GSFLs) and a lamp and ballast (for GSFLs only). For new

construction, renovation, and major retrofit GSFL purchase events, DOE also added 2.5 minutes to the labor times when installing lamps and ballasts to account for the installation of a luminaire disconnect. DOE added this additional installation time because the 2005 National Electric Code requires a means for disconnecting luminaires before they are serviced for lamp or ballast replacements.¹¹

Table 8.2.4 Relamping Times for General Service Fluorescent Lamps and Incandescent Reflector Lamps*

Lamp Type	Spot Relamp Time minutes	Group Relamp Time minutes	Average Relamp Time minutes	Time to Install Lamps and Ballasts** minutes
General Service Fluorescent Lamps (Commercial and Industrial)				
2-Lamp Fixture - 4-Foot Medium Bipin, 4-Foot Miniature Bipin	27.0	14.0	23.8	30.0
4-Lamp Fixture - 4-Foot Medium Bipin	28.0	15.0	24.8	40.0
2-Lamp Fixture - 8-Foot SP Slimline	20.5	10.5	16.8	55.0
2-Lamp Fixture - 8-Foot RDC HO	26.5	13.5	22.5	60.0
Incandescent Reflector Lamps (Commercial)				
All			4.0	N/A
* GSFL labor times are from the 2011 Ballast Rule. IRL labor times are from <i>RS Means</i>. DOE assumed that residential sector consumers install their own lamps when replacing lamps; thus, DOE only modeled residential sector installation costs when entire lamp-and-ballast systems are installed, and only the times in the “Time to Install Lamps and Ballasts” column apply. ** For new construction, renovation, and major retrofit GSFL purchase events, DOE increased labor times by 2.5 minutes to allow for the installation of a luminaire disconnect.				

For lamp-and-ballast installations, DOE derived labor rates for electricians and helpers from *RS Means*. Labor rates are the sum of the wage rate, employer-paid fringe benefits (*i.e.*, vacation pay, employer-paid health, and welfare costs), and any appropriate training and industry advancement funds costs. An electrician’s average hourly rate with overhead and profit is typically \$79.65 (in 2012\$), and a helper’s average hourly rate is \$54.55 (in 2012\$). As in the 2011 Ballast Rule, DOE assumed that 50 percent of the electrician labor rate and 50 percent of the helper labor rate (for a total of \$67.10 in 2012\$) make up the lamp-and-ballast installation rate.

For lamp replacements in the commercial sector, DOE assumed that the task is performed by a general maintenance worker. DOE obtained the labor rate of \$16.93 using the median hourly rate from the U.S. Bureau of Labor Statistics for a General Maintenance Worker.¹² Using these labor rates and the labor times listed in Table 8.2.4, DOE derived the average cost to install a lamp and the average cost to install a lamp and ballast. Table 8.2.5 lists the calculated labor rates.

Table 8.2.5 Relamping and Lamp-and-Ballast Labor Cost for General Service Fluorescent Lamps and Incandescent Reflector Lamps

Lamp Type	Relamping Labor Cost (2012\$)	Labor Cost to Install Lamps and Ballast* (2012\$)
General Service Fluorescent Lamp (Commercial and Industrial)		
2-Lamp Fixture, 4-Foot Medium Bipin and 4-Foot Miniature Bipin	\$6.70	\$33.55
4-Lamp Fixture, 4-Foot Medium Bipin	\$6.98	\$44.73
2-Lamp Fixture, 8-Foot SP Slimline	\$4.74	\$61.51
2-Lamp Fixture, 8-Foot RDC HO	\$6.34	\$67.10
Incandescent Reflector Lamps (Commercial)		
All	\$1.13	N/A
*For new construction, renovation, and major retrofit GSFL purchase events, DOE increased the labor cost to install lamps and ballast by \$2.80 (in 2012\$) to allow for the installation of a luminaire disconnect.		

8.2.3 Operating Cost Inputs

The operating cost represents the costs incurred in the operation of the lamp or lamp-and-ballast system. Table 8.2.6 lists the inputs for operating costs. The analysis period, discount rate, and compliance date of the standard are inputs to the operating cost and operating cost present value calculations. The electricity consumption for the baseline and other ELs enable comparison of standards' operating costs.

Table 8.2.6 Inputs for Operating Costs

Annual Operating Hours
Power Rating
Lighting Controls
Electricity Prices
Electricity Price Trends
Discount Rate
Analysis Period

The annual operating hours are the estimated hours that a lamp is in use during one year. Power rating refers to the rate of site energy usage associated with operating the lamp or lamp-and-ballast system. DOE uses both annual operating hours and power rating to calculate the total annual energy consumption. Electricity prices used in the analysis are the price per kilowatt-hour in cents or dollars paid by each consumer for electricity. DOE used electricity price trends to forecast electricity prices for future year analysis. Using these trends along with the electricity price and annual energy consumption, DOE calculated the energy cost in each year. DOE defines energy cost by the following equation:

$$\begin{aligned}
 OC &= E_{cons} \times EP \times EPT \\
 &= (PWR \times OH) \times EP \times EPT
 \end{aligned}
 \tag{Eq. 8.4}$$

Where:

<i>OC</i>	=	operating costs in 2012\$,
<i>E_{cons}</i>	=	annual energy consumed,
<i>EP</i>	=	electricity price in 2012\$,
<i>EPT</i>	=	electricity price trend factor relative to 2012,
<i>PWR</i>	=	power rating (rate of energy use, measured in watts), and
<i>OH</i>	=	annual operating hours.

The remainder of this section provides information about each of the above input variables that DOE used to calculate the operating costs for GSFLs and IRLs.

8.2.3.1 Annual Operating Hours

The energy use characterization (see chapter 6 of this NOPR TSD) details how DOE determines the annual energy consumption for baseline and standards-compliant products. An important input for determining the energy consumption is the total hours per year that the product is in operation. DOE also used the operating hours to calculate the lamp service life, which DOE ultimately uses to calculate the total replacement cost and residual value.

As described in chapter 6 of this NOPR TSD, DOE established operating hour distributions for GSFLs and IRLs. In conjunction with data from the LMC, DOE used data from EIA's CBECS 2003, RECS 2009, and MECS 2006. These EIA studies provide information on the distribution of buildings within the United States by building type and census division. DOE associated the LMC's lamp distribution and operating hour data by building type with the EIA's data by building type and census division to derive operating hours for GSFLs and IRLs by census division and large states. This allowed DOE to correlate its electricity price distribution and sales tax distribution (see chapter 7 of this NOPR TSD) with its operating hour distribution by census division and large state in the LCC spreadsheet. Table 8.2.7 presents the mean operating hours for GSFLs and IRLs for each sector.

Table 8.2.7 Average Operating Hours by Sector and Lamp Type

Sector	Lamp Category	Average Annual Operating Hours <i>hours/year</i>
Residential	GSFL	634
	IRL	763
Commercial	GSFL	4,065
	IRL	4,532
Industrial	GSFL	4,587

8.2.3.2 Power Rating

As described in the energy use and end load characterization (chapter 6 of this NOPR TSD), DOE used the power rating (in watts) and the annual operating hours (in hours) to calculate the annual energy usage (in kilowatt-hours) of the lamp and lamp-and-ballast system designs that DOE considered.

General Service Fluorescent Lamps

Because a fluorescent lamp requires a ballast to operate, DOE analyzed these lamps as systems consisting of both lamps and ballasts. Therefore, in the “lamp replacement” and “lamp-and-ballast replacement” scenarios, the system input power represents the energy consumption rate of the lamps and their associated ballast, and therefore is different than simply the rated lamp power alone. When a lamp is paired with ballasts with different ballast factors (BFs), the lamp-and-ballast systems have different power ratings. See chapter 6 of this NOPR TSD for detailed results showing power ratings and annual energy consumption estimates in each market sector for a given a BF and lamp power.

Incandescent Reflector Lamps

Because an IRL system consists solely of a lamp, the system’s annual energy use is simply the product of the rated power and operating hours of the lamp. Detailed tables depicting the power rating and annual energy consumption for all of the IRL designs are available in chapter 6 of this NOPR TSD.

8.2.3.3 Electricity Prices

DOE estimated electricity prices for residential, commercial, and industrial consumers in each of the 13 regions and large states by using EIA Form 861 data.¹³ Table 8.2.8 lists the 13 geographic regions. The EIA publishes Form 861 data annually, which include annual electricity sales in kilowatt-hours; revenues from electricity sales; and number of consumers for the residential, commercial, and industrial sectors for every utility serving final consumers. The calculation of an average electricity price requires two steps:

- 1) For each utility, estimate an average residential, commercial, or industrial price by dividing the residential, commercial, or industrial revenues by residential, commercial, or industrial sales.
- 2) Calculate a regional average price, weighting each utility with consumers in a region by the number of residential, commercial, or industrial consumers served in that region.

The calculation uses the most recent available EIA data at the time the analysis was conducted, from 2011. DOE scaled the EIA data to 2012 using the consumer price index and the electricity price trends. For each sector, DOE calculated a weighted national average using the probability of a GSFL or IRL in each region or large state. Table 8.2.8 shows the results for each geographic region and the U.S. weighted average for each sector.

Table 8.2.8 Electricity Prices by Census Division, 2012

Census Division	Electricity Prices, 2012		
	Residential	Commercial	Industrial
	2012\$/kWh	2012\$/kWh	2012\$/kWh
New England	\$0.156	\$0.141	\$0.120
Middle Atlantic	\$0.143	\$0.121	\$0.083
East North Central	\$0.119	\$0.097	\$0.066
West North Central	\$0.101	\$0.084	\$0.086
South Atlantic	\$0.110	\$0.090	\$0.068
East South Central	\$0.100	\$0.098	\$0.069
West South Central	\$0.091	\$0.081	\$0.063
Mountain	\$0.105	\$0.088	\$0.065
Pacific	\$0.114	\$0.106	\$0.061
New York State	\$0.191	\$0.160	\$0.084
California	\$0.147	\$0.132	\$0.096
Texas	\$0.110	\$0.099	\$0.076
Florida	\$0.114	\$0.097	\$0.080
U.S. Weighted Average	\$0.122	\$0.106	\$0.077

8.2.3.4 Electricity Price Trend

The electricity price trend projects the future cost of electricity throughout the analysis period. DOE normally calculates the LCC and PBP using three separate projections from *AEO*: reference, low economic growth, and high economic growth. The high and low growth cases show the projected effects of alternative economic growth assumptions on energy markets. Together, these three cases reflect the uncertainty of electricity price trends in the forecast period.

Figure 8.2.1 through Figure 8.2.3 show the residential, commercial, and industrial electricity price trends, respectively, based on the three *AEO 2013* projections. The LCC results presented in this chapter are based on the *AEO 2013* reference case. Appendix 8B contains LCC results based on the high and low economic growth cases.

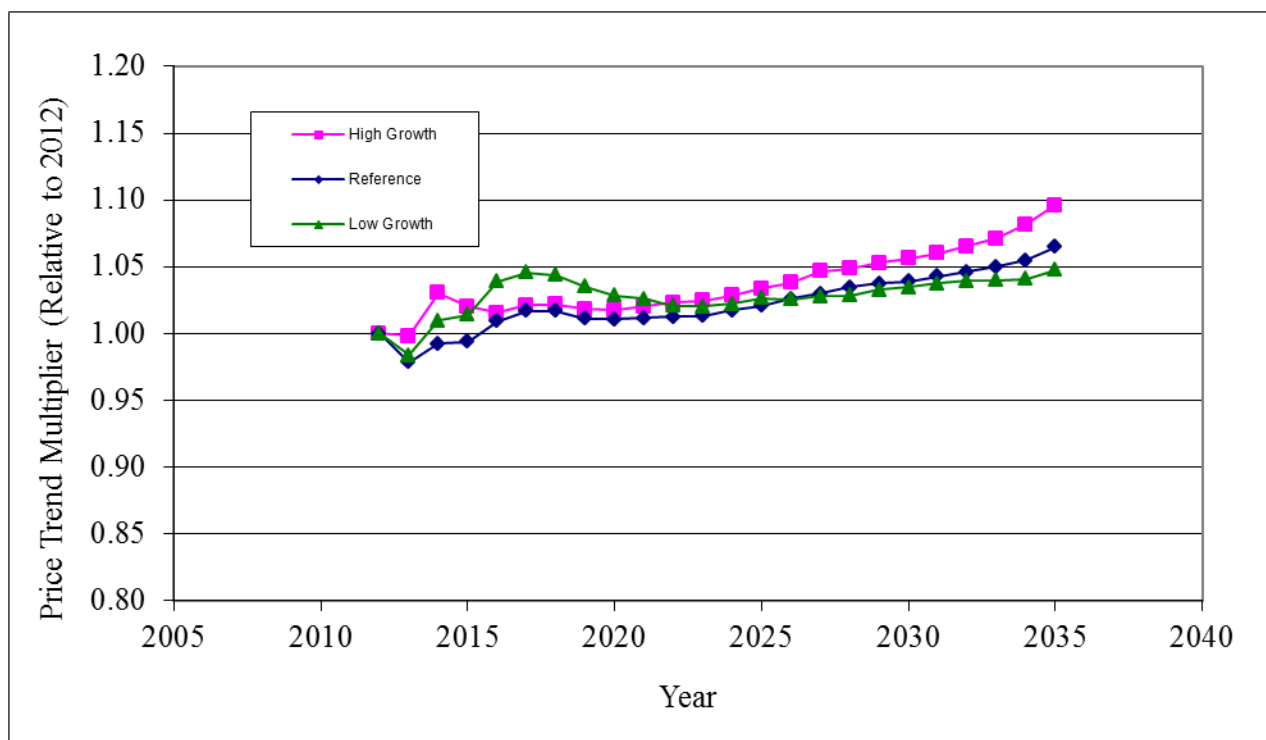


Figure 8.2.1 Residential Sector Electricity Price Trend

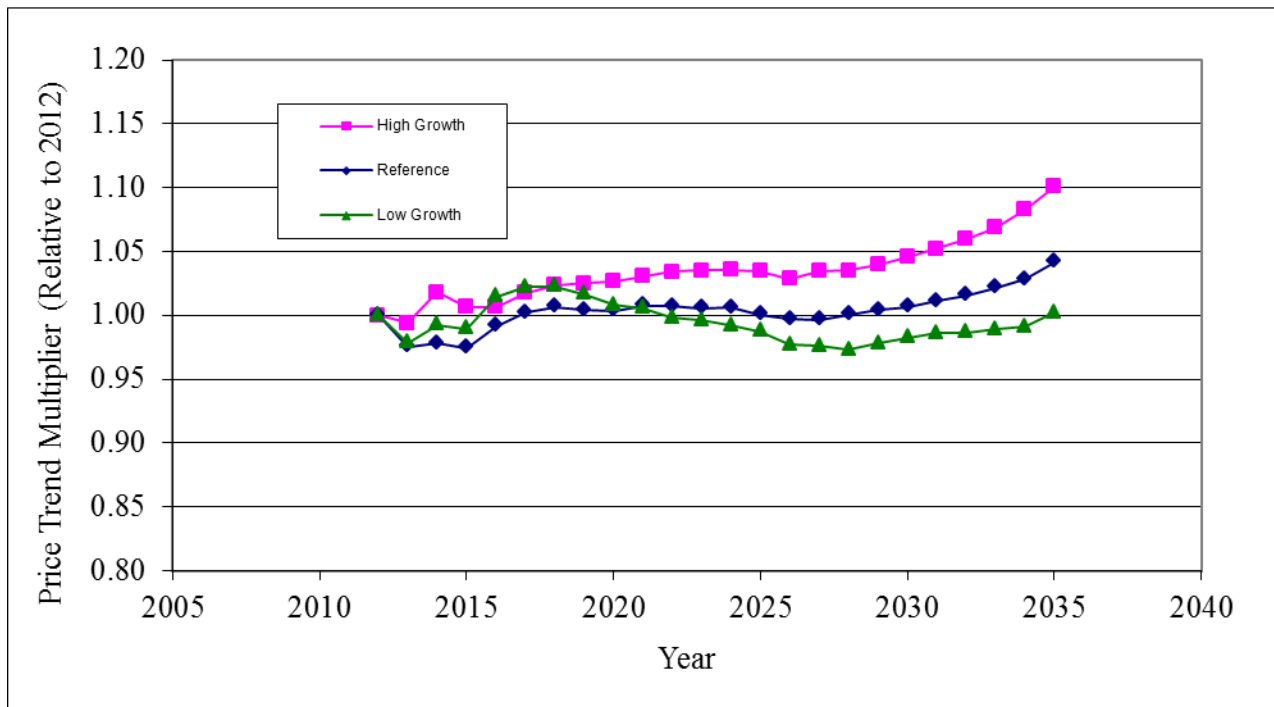


Figure 8.2.2 Commercial Sector Electricity Price Trend

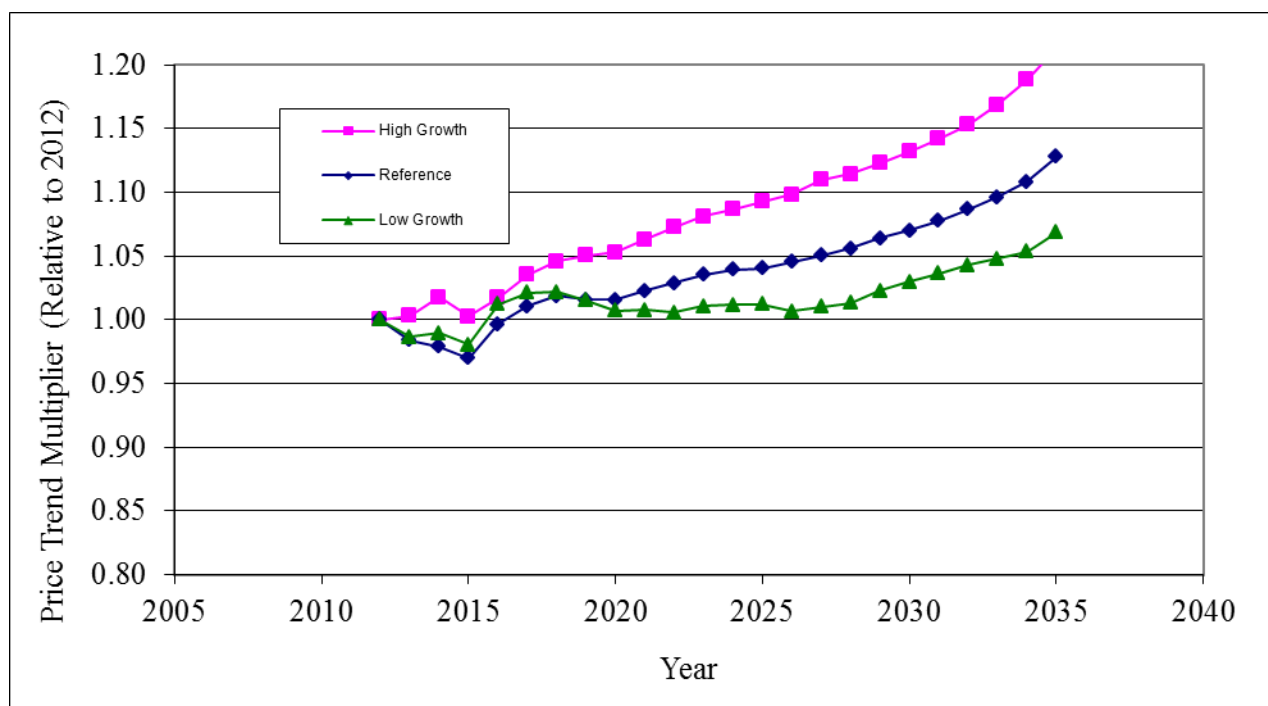


Figure 8.2.3 Residential Sector Electricity Price Trend

The LCC spreadsheet uses these electricity price trends to project electricity prices into the future, and then multiplies them by the annual energy usage. Both the LCC spreadsheets and the LCC results tables in this chapter present the resulting operating costs.

8.2.4 Lifetime

DOE defined lifetime as the age in hours of operation when a lamp or ballast is retired from service. DOE used published manufacturer literature, when available, to derive lamp lifetimes.

Similar to the calculation of relamping costs, DOE averaged the impact on lifetime of group versus spot relamping by their percent occurrence for GSFLs in the commercial and industrial sectors. See section 8.2.2.3 for further discussion of relamping costs and the percent occurrences of group versus spot relamping. DOE assumed that residential sector consumers replace their lamps either when they fail or when the associated fixture is removed; thus, there are no spot or group relamping lifetime impacts on residential sector GSFLs. See section 8.2.8 for further details on residential sector GSFL consumer behavior. In spot relamping, consumers replace failed lamps, at 100 percent of their rated life, on a one-by-one basis. In group relamping, consumers replace all the lamps in a fixture or area at a predetermined time. This latter method is the most economical approach as it significantly reduces associated labor costs. During group relamping, a consumer removes and replaces a collection of lamps that are near the end of their lives at once as a way of avoiding the failure of any individual lamp in the collection. Thus, some of the lamps in the collection will still have life remaining even though they are being replaced. DOE assumed that a GSFL subject to group relamping practices operates for 85 percent of its rated life based on information obtained in manufacturer interviews. DOE applied a life impact

factor to the rated lifetimes from the manufacturer literature for the GSFLs it analyzed. DOE then weighted this rated lifetime at which group and spot relamping occurs by the percent occurrence of these events to determine the percent of rated lifetime to use in the analysis. For 4-foot medium bipin (MBP) lamps and 4-foot miniature bipin (MiniBP) lamps, the average lifetime DOE used in the analysis was 96 percent of the rated lifetime. For 8-foot SP slimline lamps, the average lifetime was 94 percent of the rated lifetime. For 8-foot RDC HO lamps, the average lifetime was 95 percent of the rated lifetime. DOE did not assume an impact on lifetime due to group relamping for IRLs.

As discussed in the technology assessment (see chapter 3 of this NOPR TSD), many technology options to improve GSFL and IRL efficacies affect the lifetime of the lamp. For this reason, the baseline and standard level designs for the LCC and PBP analyses have a wide range of lifetimes.

For ballasts in the commercial and industrial sectors, DOE used the average ballast lifetime used in the 2011 Ballast Rule (49,054 hours). Using DOE's estimate of 49,054 hours and average operating hours for GSFLs in the commercial sector, the lifetime of an average ballast is approximately 12.1 years. This lifetime is consistent with a study on the "measure life" of ballasts (*i.e.*, the true service life of a ballast in the field), which found that the average ballast lifetime after a retrofit in the commercial sector is 13 years, and the average ballast lifetime after new construction is 15 years.¹⁴ DOE found in a separate measure life report that the average fixture and ballast in the residential sector lasts for 15 years, as discussed in section 8.2.3.1. Therefore, in its residential sector analysis for GSFLs, DOE established 15 years as the average ballast lifetime in the residential sector, regardless of operating hours.¹⁵ This is equivalent to 9,514 hours at average operating hours of 634 hours per year.

8.2.5 Replacement Cost

As stated earlier, the lifetime is the age (total hours in operation) at which the lamp or components of a lamp system are retired from service. The lifetime divided by the operating hours yields the service life of the lamp in years. Replacement costs include the labor and materials costs associated with replacing a lamp or ballast if either component must be replaced during the analysis period. By using the service life and replacement cost, DOE calculates the total replacement cost each year.

Replacement costs are the labor and materials costs associated with replacing a lamp or ballast at the end of its lifetime. Because the lifetimes of GSFL and IRL designs can vary, at times it is necessary to replace a lamp within the analysis period. Generally, if the service life of a more efficacious lamp is less than the analysis period, those lamps will require replacement to reach the end of the analysis period. Each year in which a lamp reaches the end of its life, a new lamp is purchased and installed, and the first cost and installation cost of the new lamp are discounted back to the base year of the analysis period. For IRLs in all sectors, the replacement cost is the total installed cost of the lamp because there is no ballast in the analysis.

During years in which replacement of a lamp is necessary, DOE based the replacement costs on the total installed cost inputs, as seen in the following equation:

$$\begin{aligned}
 RC &= FPP + INST \\
 &= PRICE \times MU_{TAX} + INST
 \end{aligned}
 \tag{Eq. 8.5}$$

Where:

<i>RC</i>	=	replacement cost in 2012 dollars,
<i>FPP</i>	=	final product price (i.e., consumer price for the product only, including sales tax) in 2012 dollars,
<i>INST</i>	=	installation cost in 2012 dollars,
<i>PRICE</i>	=	end-user product price in 2012 dollars, and
<i>MU_{TAX}</i>	=	sales tax.

For the years when no replacement is necessary, the replacement costs are zero.

8.2.6 Disposal Cost

When a GSFL fails, some consumers choose to recycle the lamp. The cost of recycling the GSFL is its disposal cost. DOE performed research on recycling costs for GSFLs and found that, on average, disposing of a GSFL costs about 10 cents per linear foot.¹⁶ A report released by the Association of Lighting and Mercury Recyclers in 2004 noted that consumers recycle approximately 30 percent of lamps used in the commercial sector and 2 percent of lamps in the residential sector.¹⁷ Because a relatively large percentage of consumers recycle lamps in the commercial and industrial sectors, DOE applied a cost of 10 cents per linear foot in 2012\$ for each recycled or replaced lamp during the LCC analysis period. Thus, for 4-foot lamps, the disposal cost is \$0.40 per lamp in 2012\$, while for 8-foot lamps, the disposal cost is \$0.80 per lamp in 2012\$. The disposal cost also impacts the residual value of lamps that operate beyond the end of the analysis period (described in 8.2.11). DOE assumed that commercial and industrial consumers pay recycling costs for approximately 30 percent of lamp failures. Because few residential sector consumers recycle lamps, DOE did not apply the disposal costs to this sector. DOE did not apply disposal costs for IRLs in any sector because consumers do not pay for their disposal.

8.2.7 Analysis Period

The analysis period is the time span over which DOE calculates the LCC. To account for variability in lifetime of lamp designs, DOE developed a consistent analytical time period—comparing more-efficacious lamps to a baseline lamp over the lifetime of the baseline lamp in the analysis. When this analysis period was shorter than the lifetime of the replacement lamp, DOE accounted for the remaining life of the replacement lamp as a residual value. When the analysis period was longer than the lifetime of the replacement lamp, a second replacement lamp is installed, and if any operating life of that second replacement lamp remained at the end of the analysis period, then DOE added its residual value back into the LCC. By using the average lamp lifetimes divided by the annual operating hours, DOE calculates the lamp service lifetime in years.

For the IRL and the commercial and industrial sector GSFL analyses, DOE based the analysis period on the baseline lamp life in the analysis divided by the annual operating hours of

that lamp. If the user chooses to run the LCC using weighted average values (*i.e.*, in “sample calculation” mode), then the analysis period is based on the baseline lamp life for that analysis divided by the average annual operating hours for that lamp in a chosen sector, or a multiple thereof. For example, the baseline lifetime for the IRL is 1,500 hours. If the user chooses to analyze this lamp in the commercial sector, then the analysis period is the lamp lifetime of 1,500 hours divided by the average annual operating hours of IRLs in the commercial sector (4,532 hours per year), or 0.3 years. To allow users to compare the cost of IRLs over multiple lamp lifetimes, one can select a multiple of this analysis period (*i.e.*, 0.6, 0.9, or 1.2 years). If the user chooses to run the LCC using the Monte Carlo simulation (*i.e.*, in “Crystal Ball” mode), the analysis period is based on the baseline lamp life for the analysis divided by the annual operating hours chosen by Crystal Ball[®]. For example, if Crystal Ball[®] selects a building that is used for religious worship, the analysis period for the 1,500 hour baseline IRL for that selection will be based on a lamp lifetime of 1,500 hours divided by the annual operating hours of IRLs in a building used for religious worship (4,417 hours per year), or 0.3 years. Users cannot select a multiple of this analysis period when using the Monte Carlo simulation.

8.2.8 Residential GSFL Analysis

As described in section 8.2.4, the average useful lifetime of ballasts in the residential sector is approximately 15 years, regardless of operating hours.¹⁸ DOE had to make additional assumptions regarding consumer behavior for the residential GSFL failure scenario because the lamp life exceeds the ballast life in this sector for the lamp failure scenario. DOE considered two types of consumer behavior for the lamp failure scenario in the GSFL residential sector. In the first kind of consumer behavior, consumers dispose of their lamps when replacing a ballast, regardless of how much lifetime the lamps have remaining. In the second kind of consumer behavior, residential GSFL consumers preserve their lamps when replacing a fixture, then install the lamps on the new fixture. Because the lamps live for their entire rated lifetimes, a lamp failure event can be analyzed. DOE received feedback that the first type of consumer behavior, where consumers dispose of their lamps when replacing a ballast, is more common. Thus, DOE assumed the first type of consumer behavior occurred in the main LCC results presented in this chapter. DOE conducted a sensitivity analysis assuming the second type of consumer behavior (see appendix 8B of this NOPR TSD).

For the ballast failure and new construction and renovation events in the residential sector, DOE used average operating hours and assumed that a consumer would purchase a new lamp when purchasing a ballast. DOE modeled only non-lamp-preserving consumers for the ballast failure and new construction and renovation events in order to obtain a lower bound of LCC savings. Because the lamp lifetime exceeds the ballast lifetime under average operating hours conditions, DOE assumed that the ballast lifetime of 15 years limits the lamp lifetime. Therefore for GSFLs in the residential sector, the useful life of the baseline lamp and therefore the analysis period is 15 years for the ballast failure and new construction and renovation events.

8.2.9 Discount Rate

The discount rate is the rate at which DOE discounts future expenditures to establish their present values. DOE derived the discount rates for this rulemaking separately for residential and commercial/industrial consumers. For residential consumers, DOE estimated the discount rate by

looking across all possible debt or asset classes that might be used to purchase lamps. For the commercial and industrial consumers, DOE estimated the cost of capital for commercial and industrial companies by examining both debt and equity capital, and developed an appropriately weighted average of the cost to the company of equity and debt financing.

8.2.9.1 Residential Discount Rate

GSFLs and IRLs are comparatively low-cost products for households to replace. With retail prices typically ranging from four dollars to twenty-two dollars, households typically purchase lamps as needed. DOE's approach involves identifying all possible debt or asset classes that might be used to purchase replacement products, including household assets that might be affected indirectly.^a DOE did not include debt from primary mortgages and equity of assets considered non-liquid (such as retirement accounts), since these would likely not be used to finance replacement lamp purchases. DOE estimated the average shares of the various debt and equity classes in the average U.S. household equity and debt portfolios using data from the Federal Reserve Board's *Survey of Consumer Finances (SCF)* for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010.¹⁹ Table 8.2.9 shows the average shares of each considered class. DOE used the mean share of each class across the eight survey years (21 years) as the basis for estimating household financing of lamps and lighting products.

^a An indirect effect would arise if a household sold assets to pay off a loan or credit card debt that might have been used to finance the actual lamp purchase.

Table 8.2.9 Average Percentage Shares of Household Debt and Equity Types

Type	1989 SCF (%)	1992 SCF (%)	1995 SCF (%)	1998 SCF (%)	2001 SCF (%)	2004 SCF (%)	2007 SCF (%)	2010 SCF (%)	Mean (%)
Home equity loans	2.2	1.9	0.9	1.0	1.2	2.9	2.5	3.0	2.0
Credit cards	0.0	2.2	2.6	2.2	1.7	2.0	2.5	2.2	1.9
Other installment loans	3.1	1.8	1.4	1.7	1.1	1.4	1.2	1.3	1.6
Other residential loans	0.0	7.0	5.3	4.4	3.1	5.9	7.3	7.4	5.1
Other line of credit	1.2	0.6	0.4	0.0	0.3	0.5	0.3	0.8	0.5
Checking accounts	6.3	4.8	4.9	4.0	3.7	4.3	3.5	4.4	4.5
Savings & money market	20.9	19.3	14.3	13.1	14.5	15.4	13.3	16.4	15.9
Certificate of deposit (CD)	15.8	12.0	9.5	7.1	5.5	6.0	6.6	6.8	8.7
Savings bond	2.4	1.7	2.2	1.1	1.2	0.9	0.7	0.6	1.3
Bonds	15.0	12.6	10.7	7.1	8.0	8.6	6.8	7.4	9.5
Stocks	24.4	24.7	26.4	37.7	38.1	28.4	29.3	23.7	29.1
Mutual funds	8.7	11.4	21.3	20.5	21.6	23.7	26.0	26.0	19.9
Total	100	100	100	100	100	100	100	100	100

DOE estimated interest or return rates associated with each type of equity and debt using data on interest rates for loans, credit cards, and lines of credit from the same Federal Reserve Board SCF in 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010. The top half of Table 8.2.10 shows the average nominal interest rates in each year and the inflation rates used to calculate real rates (Using the Fisher formula).^b For home equity loans, DOE calculated effective interest rates in a similar manner as for mortgage rates, since interest on such loans is tax deductible. The bottom half of the table shows the average effective real interest rates in each year and the mean rate across all the years. Because the interest rates for each debt carried by households in these years were established over a range of time, DOE believes they are representative of rates that may apply when amended standards require compliance.

^b Fisher formula is given by: Real Interest Rate = $[(1 + \text{Nominal Interest Rate}) / (1 + \text{Inflation Rate})] - 1$.

Table 8.2.10 Average Nominal and Real Interest Rates for Household Debt Classes

Type	1989 SCF	1992 SCF	1995 SCF	1998 SCF	2001 SCF	2004 SCF	2007 SCF	2010 SCF	Mean
Nominal Interest Rates %									
Home Equity Loans	8.4	6.2	7.0	6.8	6.0	3.6	5.8	3.7	5.9
Credit Cards*	-	-	14.1	14.0	13.9	11.1	12.4	14.0	13.2
Other Installment Loans	8.4	7.5	8.5	7.6	8.3	8.1	8.8	13.2	8.8
Other Residential Loans	9.8	8.9	8.3	8.0	7.7	6.0	6.4	5.8	7.6
Other Line of Credit	14.4	12.5	11.6	11.6	9.4	7.6	9.6	8.5	10.6
Inflation Rate	4.8	3.0	2.8	1.6	2.8	2.7	2.8	1.6	
Real Interest Rates %									
Home Equity Loans	4.5	3.8	4.8	5.4	3.7	1.5	3.5	1.5	3.6
Credit Cards*	-	-	11.0	12.1	10.9	8.4	9.6	10.3	10.4
Other Installment Loans	4.6	5.7	6.5	6.4	6.3	6.1	6.8	7.3	6.2
Other Residential Loans	4.6	5.6	5.3	6.1	4.7	3.2	3.4	2.9	4.5
Other Line of Credit	9.3	9.3	8.4	9.7	6.2	4.9	6.7	5.7	7.5

* No interest rate data available for credit cards in 1989 or 1992.

To account for variation among new households, DOE sampled a rate for each household from a distribution of rates for each of the above debt classes. DOE developed a probability distribution of interest rates for each debt class based on the *SCF* data. Appendix 8C of this NOPR TSD presents the probability distribution of interest rates for each debt class that DOE used in the LCC and PBP analyses.

Similar rate data are not available from the *SCF* for the asset classes, so DOE derived data for these classes from national historical data. The interest rates associated with certificates of deposit (CDs),²⁰ savings bonds,²¹ and bonds (AAA corporate bonds)²² are from Federal Reserve Board time-series data 1982-2012. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data covering 1984-2012.²³ The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500 1982-2012.²⁴ The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year from 1982 to 2012. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year. Average nominal and real interest rates for the classes of assets are shown in Table 8.2.11. Because the interest and return rates for each asset type cover a range of time, DOE believes they are representative of rates that may apply when amended standards take effect.

Table 8.2.11 Average Nominal and Real Interest Rates for Household Equity Types

Type	Average Nominal Rate %	Average Real Rate %
Checking Accounts	0.0	0.0
Savings and Money Market	5.0	2.0
CDs	4.9	1.9
Savings Bonds	7.4	4.3
Bonds	7.4	4.4
Stocks	10.7	7.6
Mutual Funds	10.0	6.8

To account for variation among new households, DOE sampled a rate for each household from a distribution of rates for each of the above asset types. DOE developed a normal probability distribution of interest rates for each asset type by using the mean value and standard deviation from the distribution. Appendix 8C of this NOPR TSD presents the probability distribution of interest rates for each asset type that DOE used in the LCC and PBP analysis.

Table 8.2.12 summarizes the mean real effective rates of each type of equity or debt. DOE determines the average share of each debt and asset using *SCF* data for 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010. Each year of *SCF* data provides the debt and asset shares for U.S. households. DOE averaged the debt and asset shares over the eight years of survey data to arrive at the shares shown in the following table. The average rate across all types of household debt and equity, weighted by the shares of each class, is 5.2 percent.

Table 8.2.12 Shares and Interest or Return Rates Used for Household Debt and Equity Types

Type	Average Share of Household Debt Plus Equity %*	Mean Effective Real Rate %**
Home Equity Loans	2.0	3.6
Credit Cards	1.9	10.4
Other Installment Loans	1.6	6.2
Other Residential Loans	5.1	4.5
Other Line of Credit	0.5	7.5
Checking Accounts	4.5	0.0
Savings and Money Market Accounts	15.9	2.0
CDs	8.7	1.9
Savings Bonds	1.3	4.3
Bonds	9.5	4.4
Stocks	29.1	7.6
Mutual Funds	19.9	6.8
Total/Weighted Average Discount Rate	100	5.2
* Not including primary mortgage or retirement accounts.		
** Adjusted for inflation and, for home equity loans, loan interest tax deduction.		

8.2.9.2 Commercial Discount Rate

Most companies use both debt and equity capital to fund investments; for most companies, therefore, the cost of capital is the weighted average of the cost of equity and debt financing to the firm.²⁵ DOE estimated the cost of equity financing using the Capital Asset Pricing Model (CAPM). The CAPM, among the most widely used models to estimate the cost of equity financing, assumes that the cost of equity is proportional to the amount of systematic risk associated with a firm. For example, the cost of equity financing tends to be high when a firm faces a large degree of systematic risk, and the cost tends to be low when the firm faces a small degree of systematic risk.

The degree of systematic risk facing a firm and the subsequent cost of equity financing are determined by several variables, including the risk coefficient of a firm (beta, or B), the expected return on risk-free assets (R_f), and the additional return expected on assets facing average market risk (known as the equity risk premium, or ERP). The beta indicates the degree of risk associated with a given firm, relative to the level of risk (or price variability) in the overall stock market. Betas usually vary between 0.5 and 2.0. A firm with a beta of 0.5 faces half the risk of other stocks in the market; a firm with a beta of 2.0 faces twice the overall stock market risk.

Following this approach, the cost of equity financing for a particular company is by the equation:

$$k_e = R_f + (\beta \times ERP) \quad \text{Eq. 8.6}$$

Where:

k_e	=	the cost of equity for a company, expressed in dollars,
R_f	=	the expected return of the risk-free asset, expressed in dollars,
β	=	the risk coefficient, and
ERP	=	the expected equity risk premium, expressed in dollars.

The cost of debt financing (k_d) is the yield or interest rate paid on money borrowed by a company (raised, for example, by selling bonds). As defined here, the cost of debt includes compensation for default risk and excludes deductions for taxes.

DOE estimated the cost of debt for companies by adding a risk adjustment factor to the current yield on long term corporate bonds (the risk-free rate). This procedure is used to estimate current and future company costs to obtain debt financing. The adjustment factor is based on indicators of company risk, such as credit rating or variability of stock returns.

The discount rate of companies is the weighted average cost of debt and equity financing, less expected inflation. DOE estimated the discount rate using the equation:

$$k = k_e \times w_e + k_d \times w_d \quad \text{Eq. 8.7}$$

Where:

k = the (nominal) cost of capital,
 k_e and k_d = the expected rates of return on equity and debt, respectively, and
 w_e and w_d = the proportion of equity and debt financing, respectively.

The real discount rate deducts expected inflation from the nominal rate.

The expected return on risk-free assets, or the risk-free rate, is from the Damodaran Online site (a private website associated with New York University's Stern School of Business, which aggregates information on corporate finance, investment, and valuation).²⁶ The ERP represents the difference between the expected (average) stock market return of the S&P 500 over a 40-year time period and the risk-free rate. As Table 8.2.13 shows, DOE used an ERP estimate of 5.8 percent, which it calculated from the risk-free rate described above and S&P 500 returns from the Damodaran Online site.

DOE calculated an expected inflation of 1.9 percent from the average of the projected change in gross domestic product (GDP) prices in the *Fiscal Year 2014 Analytical Perspectives*.²⁷ DOE obtained the cost of debt, percent debt financing, and systematic firm risk from the Damodaran Online website. Table 8.2.13 shows average values across all public companies considered in the analysis. However, the cost of debt, percent debt financing, and systematic firm risk vary by sector.

Table 8.2.13 Variables Used to Estimate Company Discount Rates

Variable	Symbol	Average Value %	Source
Risk-Free Asset Return	R_f	1.8	Damodaran Online
Equity Risk Premium	ERP	5.8	Damodaran Online
Expected Inflation	R	1.9	Fiscal Year 2014 Analytical Perspectives
Cost of Debt (After Tax)	k_d	2.7	Damodaran Online
Percent Debt Financing	w_d	22.0	Damodaran Online
Systematic Firm Risk	B	1.48	Damodaran Online

In the commercial sector, commercial building property owners, commercial companies, industrial companies, and the Government all purchase and own lamps. DOE used a sample of 4,359 companies to represent lamp purchasers. DOE obtained the cost of debt, the firm beta, the percent of debt and equity financing for each company, the risk-free return, and the equity risk premium from Damodaran Online.

DOE estimated the cost of debt financing for these companies from the long term Government bond rate (risk-free rate) and the standard deviation of the stock price. For Government-office-type owners, the discount rate represents an average of the Federal rate and the state and local bond rate. DOE drew the Federal rate directly from the U.S. Office of Management and Budget discount rate for investments in Government building energy efficiency.²⁸ DOE estimated the state and local discount rate from the interest rate on state and

local bonds between 1982 and 2012.²⁹ DOE used this information to estimate the weighted average cost of capital for the sample of companies included in the commercial property owner, commercial, and industrial company database.

One can view the cost of capital as the discount rate applied to reduce the future value of typical company project cash flows. It is a nominal discount rate, since both stock and bond expected returns already account for anticipated inflation. Deducting expected inflation from the cost of capital provides estimates of the real discount rate by ownership category (see Table 8.2.14). The mean real discount rate for these companies varies between 2.2 percent (Government offices) and 6.3 percent (commercial property owners).

Table 8.2.14 Real Discount Rates by Lamp Ownership Category

Ownership Category	SIC Codes*	Mean Real Discount Rate %	Standard Deviation %	Number of Observations
Industrial Companies	1 - 4	6.3	1.9	2,606
Commercial Companies	5 - 8	5.0	2.1	1,751
Commercial Property Owners	6720	6.3	0.1	2
Government Offices	N/A	2.2	3.0	N/A
* SIC Codes refer to the U.S. Standard Industrial Classification system. Source: Navigant Consulting, Inc., calculations based on firms sampled from the Damodaran Online website.				

DOE's approach for estimating the cost of capital provides a measure of the discount rate spread as well as the average discount rate. DOE inferred the discount rate spread by ownership category from the standard deviation, which ranges between 0.1 percent and 3.0 percent (Table 8.2.14).

Different combinations of commercial property owners and commercial, industrial, and Government buyers purchase the lamp types considered in the LCC analysis. Accordingly, DOE constructed the discount rates associated with each building sector from different combinations of commercial property owner, commercial, industrial, and Government rates.

To estimate the share of each ownership category in total commercial sector purchases of lamps, DOE used the share of each category in total commercial building square footage with lighting provided by EIA's 2003 CBECS. Table 8.2.15 presents the estimated shares of commercial lamp purchases by ownership category of commercial building space.

Table 8.2.15 Estimated Share of Lamp Purchases by Ownership Category in the Commercial Sector

Ownership Category	Percent
Property Owners and Managers	22.3
Industrial Firms	10.1
Commercial Firms	54.8
Government	12.8
Source: 2003 CBECS. * The share of total square footage occupied by property owners is actually 44.6%. However, in some of these buildings, the tenants purchase lamps. DOE assumed that this is the case for half of the square footage occupied by property owners. DOE allocated this quantity among the other categories in proportion to their shares of total square footage.	

Table 8.2.16 presents the distribution of lamp ownership for the commercial and industrial lighting sectors.

Table 8.2.16 Lamp Ownership by Sector

Sector	Property Owners %	Industrial Companies %	Commercial Companies %	Government %
Industrial	0	100	0	0
Commercial	22.3	10.1	54.8	12.8
Sources: Commercial, CBECS; Industrial, DOE estimate.				

DOE estimated discount rate distributions for the different sectors as a weighted average of the distributions for the different ownership types. The resulting weighted average discount rates are 6.3 percent for the industrial sector and 5.1 percent for the commercial sector. Table 8.2.17 summarizes the weighted average discount rates in all three sectors.

Table 8.2.17 Average Discount Rate by Sector

Sector	Discount Rate %
Industrial	6.3
Commercial	5.1
Residential	5.2

8.2.10 Compliance Date of Standard

The compliance date is the date by which lamp manufacturers must manufacture products that comply with the standard. Currently, DOE is scheduled to publish a final rule in this standards rulemaking in 2014. The compliance date of any amended energy conservation standards for these lamps must be 3 years after the publication of the final rule, (42 U.S.C. 6295(i)(3) and (i)(5)), which DOE expects to be 2017. DOE calculated the LCCs for all consumers as if each would purchase a new product in the year the standard takes effect.

However, DOE based the cost of the products on the most recent available data; all dollar values are expressed in 2012\$.

8.2.11 Residual Value

The residual value represents the remaining value of a lamp or a ballast from the end of the period of analysis to the end of the service life of the lamp or ballast. Since the analysis period is based on the lifetime of the baseline lamp for each analysis, DOE assumed lamps with lifetimes shorter than the analysis period are replaced. To account for the remaining value of lamps with remaining life to the consumer, the LCC model applies this residual value as a “credit” at the end of the analysis period, and discounts it back to the start of the analysis period. Equation 8.8 exhibits how DOE accounts for residual value in its LCC calculation. The equation for residual value is as follows:

$$RV = IC \cdot \frac{SL - [P_{Analysis} - (n \cdot SL)]}{SL} + DC \cdot \frac{P_{Analysis} - (n \cdot SL)}{SL} \quad \text{Eq. 8.8}$$

Where:

RV	=	residual value
IC	=	total installed cost of the product,
n	=	the number of replacements within the analysis period,
SL	=	the service life of the product,
DC	=	disposal cost (commercial and industrial sectors only), and
$P_{Analysis}$	=	the analysis period.

DOE determined the residual value of the product by linearly prorating the replacement cost (*i.e.*, total installed cost) and the disposal cost by the remaining service life. For example, consider a \$10 4-foot GSFL that has a service life of five years and a disposal cost of \$0.40 used to replace a baseline lamp that has a service life of three years in the commercial sector. Because the baseline lamp defines the analysis period, DOE would calculate the residual value of the lamp design as $(2 \div 5) \times \$10 + (3 \div 5) \times \$0.40$, or \$4.24. Thus, the residual value in equation 8.8 would be \$4.24, and that value would be discounted back to the start of the time period of analysis. DOE uses this equation for both lamps and ballasts installed by consumers.

8.3 PAYBACK PERIOD INPUTS

8.3.1 Definition

The PBP is the amount of time it takes the consumer to recover the assumed higher purchase cost of a more-efficacious product through lower operating costs. Numerically, the PBP is the ratio of the increase in purchase cost (*i.e.*, the cost difference between a less efficacious design and a more efficacious design) to the decrease in annual operating expenditures. This type of calculation is known as a “simple” PBP, because it does not take into account changes in operating cost over time or the time value of money. That is, the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC} \quad \text{Eq. 8.9}$$

Where:

PBP = payback period in years,

ΔIC = difference in the total installed cost between the more-efficacious standard level (efficacy levels 1, 2, etc.) and the baseline (efficacy level 0), and

ΔOC = difference in annual operating costs.

This analysis expresses PBPs in years. A PBP greater than the life of the product indicates that the increased total installed cost of the more-efficacious product is not recovered through reduced operating costs over the lifetime of that product. Because some lamp designs and lamp-and-ballast designs in the LCC and PBP analyses do not save energy and thus yield a zero ΔOC , PBPs labeled “NER” (no energy-saving replacement) indicate an incalculable PBP.

8.3.2 Rebuttable Presumption Payback Period

Section 325(o)(2)(B)(iii) of the Energy Policy and Conservation Act of 1975 (EPCA; Pub. L. 94-163) establishes a rebuttable presumption that a standard for GSFLs or IRLs is economically justified if the Secretary finds that “the additional cost to the consumer of purchasing a product complying with an energy conservation standard level will be less than three times the value of the energy. . . savings during the first year that the consumer will receive as a result of the standard, as calculated under the applicable test procedure” (42 U.S.C. 6295(o)(2)(B)(iii)) This rebuttable presumption test is an alternative path to establishing economic justification, as compared to consideration of the seven factors set forth in 42 U.S.C. 6295(o)(2)(B)(i)(I)-(VII).

DOE’s lamp test procedures measure the rate of light output per unit power consumption of a lamp (*i.e.*, lumens per watt; lm/W) rather than a measurement of energy consumption (*i.e.*, a measurement over a duration or operating time period). Therefore, to calculate energy savings for the rebuttable presumption PBP, one would need to multiply the rate of power consumption of a lamp times the usage profile of that lamp. For IRLs, energy savings calculations in the LCC and PBP analyses use both the relevant test procedures as well as the relevant usage profile. Because DOE calculated PBPs in a methodology consistent with the rebuttable presumption test for IRLs in the LCC and PBP analyses, DOE is not performing a stand-alone rebuttable presumption analysis for IRLs, as it is already embodied in the LCC and PBP analyses. For GSFLs, DOE believes that the rate of energy consumption of the lamp-and-ballast system is a more accurate measure of real world power consumption than the rate of power consumption of

the lamp as measured on a reference ballast as prescribed by the test procedure.^c Because calculations of energy savings in the LCC are based under real world conditions, DOE is also relying on standard PBPs for GSFLs.

8.3.3 Inputs

The data inputs to the PBP are the total installed cost of the product to the consumer and the first-year operating costs. The inputs to the total installed cost are the end-user product price and the installation cost incurred by a consumer at the very beginning of the analysis period. Thus, purchases and associated installation costs incurred by consumers in the middle of the analysis period are not reflected in the PBP computation. The inputs to the operating costs are the lamp or lamp-and-ballast system power rating, annual operating hours, and electricity cost. The PBP uses the same inputs as the LCC calculation described in section 8.2, except that electricity price trends are not required. Because the PBP is a “simple” (undiscounted) PBP, the required electricity cost is only for the year in which a new energy conservation standard is to take effect—in this case, 2017. The electricity price DOE used in the PBP calculation for electricity cost is the price projected for 2017, expressed in 2012\$.

8.4 LAMP PURCHASING EVENTS

DOE designed the LCC and PBP analyses for this rulemaking around scenarios where consumers need to replace a lamp; DOE collectively refers to these as “lamp purchasing events.” Each of these events may present the consumer with a different set of lamp or lamp-and-ballast designs and therefore a different set of LCC savings for a certain EL. For GSFLs, DOE identified three possible scenarios under which consumers would purchase a lamp and potentially be affected by an energy conservation standard. These scenarios are: 1) lamp failure, 2) ballast failure, and 3) new construction/renovation. Only the lamp failure and new construction and renovation events apply for IRLs because IRLs do not operate on ballasts.

The bullets below describe lamp purchasing events in more detail. In addition to these descriptions, Table 8.4.1 and Table 8.4.2 summarize the lamp purchasing events considered in this analysis for GSFLs.

- Event I: Lamp failure - This event reflects a scenario in which a consumer must replace a failed lamp. For GSFLs, this includes spot relamping (when a lamp fails) or group relamping (when a lamp is about to fail, for the commercial and industrial sectors only). DOE assumed that in the base case (the absence of an energy conservation standard) a consumer would install a baseline lamp as a replacement. However, an energy conservation standard requires a standards-compliant lamp that operates on the existing ballast. Thus, DOE expects the consumer to respond to a lamp failure with a lamp replacement of the same type of lamp.

^c For example, T8 lamps which are often operated on high-frequency electronic ballasts, may be tested and measured on a low-frequency (60 Hz) reference ballast using DOE’s test procedure, resulting in different performance characteristics than this lamp would exhibit in the field, operated on an electronic ballast.

- Event II: Ballast failure - This is a scenario for GSFLs only in which the failure of the installed ballast triggers a lamp and ballast purchase. DOE expects users who experience a ballast failure to replace it with a new ballast and corresponding baseline lamp. However, in the standards case, end-users would select a standards-compliant lamp-and-ballast combination such that the system light output stays within 10 percent of the baseline system when possible.
- Event III: New construction and renovation - This lamp purchasing event encompasses all the new fixture installations where the lighting design will be completely new or can be completely changed.

Table 8.4.1 through Table 8.4.2 outline the events and actions taken by base case and standards case consumers in response to the three events described above for all GSFL product classes by lamp diameter.

Table 8.4.1 Framework of Event-Type Scenarios for T8 Baseline Lamp Consumers

Event	Base Case Action	Standards Case Action
Type 1: Lamp Failure	Installs a baseline lamp.	Installs a reduced wattage, higher efficacy lamp such that the system light output stays within 10 percent of the baseline system, when possible.
Type 2: Ballast Failure	Installs a T8 electronic ballast and baseline lamps in the existing fixture.	Installs new T8 ballast and higher efficacy lamps such that the system light output stays within 10 percent of the baseline system, when possible.
Type 3: New Construction and Renovation	Installs a new T8 baseline system including fixture, ballast, and lamp.	Installs a new higher efficacy T8 system such that the system light output stays within 10 percent of the baseline system, when possible.

Table 8.4.2 Framework of Event-Type Scenarios for T5 Baseline Lamp Consumers

Event	Base Case Action	Standards Case Action
Type 1: Lamp Failure	Installs a baseline lamp.	Installs a reduced wattage, higher efficacy lamp such that the system light output stays within 10 percent of the baseline system, when possible.
Type 2: Ballast Failure	Installs a T5 electronic ballast and baseline lamps in the existing fixture.	Installs new T5 ballast and higher efficacy lamps such that the system light output stays within 10 percent of the baseline system, when possible.
Type 3: New Construction and Renovation	Installs a new T5 baseline system including fixture, ballast, and lamp.	Installs a new higher efficacy T5 system such that the system light output stays within 10 percent of the baseline system, when possible.

8.5 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

This section presents LCC results for each lamp and lamp-and-ballast design that DOE considers. This section uses the terms “positive LCC savings” and “negative LCC savings.” When a standard results in “positive LCC savings,” the LCC of the standards-compliant lamp is less than the LCC of the baseline lamp and the consumer benefits. A consumer is adversely affected when a standard results in “negative LCC savings” (*i.e.*, when the LCC of the standards-compliant lamp is higher than the LCC of the baseline lamp).

As stated earlier, DOE conducted a series of LCC calculations for each baseline lamp. For GSFLs, DOE considered lamp-only substitutions as well as lamp-and-ballast substitutions. For IRLs, DOE considered lamp-only substitutions. In all cases, DOE considered designs that save energy when possible and maintain light output within 10 percent of the baseline lamp or system, when possible.

DOE designed all replacement options around lamp purchasing events, described further in section 8.4. The LCC spreadsheet calculates the LCC impacts for each of these scenarios

separately. Examining the impacts on each scenario separately allows one to view the results of many sub-populations in the LCC analysis.

8.5.1 Results for General Service Fluorescent Lamps

DOE is analyzing five representative product classes for GSFLs: 4-foot MBP $\leq 4,500$ K, 8-foot SP slimline $\leq 4,500$ K, 8-foot RDC HO $\leq 4,500$ K, 4-foot T5 MiniBP SO $\leq 4,500$ K, and 4-foot T5 MiniBP HO $\leq 4,500$ K. This section presents all of the results for each of these representative product classes by lamp purchasing event and by market sector, which influence the LCC and PBP results. For each product class, DOE also presented a summary of the most pertinent results in the LCC analysis.

8.5.1.1 Product Class: 4-foot medium bipin $\leq 4,500$ K

For the 4-foot MBP $\leq 4,500$ K product class in the commercial, industrial, and residential sectors, DOE analyzes one baseline lamp, a 32 W T8. For the baseline lamp, DOE analyzes multiple lamp substitutions with each lamp substitution corresponding to the ELs' requirements.

Table 8.5.1 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 2-lamp instant start baseline lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.7 years, and average weighted lamp prices.

Table 8.5.2 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 2-lamp instant start baseline lamp operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.0 years, and average weighted lamp prices.

Table 8.5.3 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 2-lamp programmed start baseline lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 9.5 years, and average weighted lamp prices.

Table 8.5.4 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 2-lamp programmed start baseline lamp operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 8.4 years, and average weighted lamp prices.

Table 8.5.5 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 4-lamp instant start baseline lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.7 years, and average weighted lamp prices.

Table 8.5.6 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 4-lamp instant start baseline lamp operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.0 years, and average weighted lamp prices.

Table 8.5.7 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 4-lamp programmed start baseline lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 9.5 years, and average weighted lamp prices.

Table 8.5.8 presents the findings of an LCC and PBP analyses for the 4-foot 32 W T8 MBP 4-lamp programmed start baseline lamp operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 8.4 years, and average weighted lamp prices.

Table 8.5.10 presents the findings of the LCC and PBP analyses on the 4-foot 32 W T8 MBP baseline GSFL in the residential sector. The analysis period is 15 years, which represents the 15-year life of the ballast. Key inputs consist of using *AEO 2013* reference case electricity prices and average weighted lamp and ballast prices. See section 8.2.8 for a further description of residential sector GSFL consumer behavior.

The results for Event I (lamp failure) show that consumers would achieve negative LCC savings for all of the lamps at EL 1 in the commercial, industrial, and residential sectors for all of the scenarios (2-lamp and 4-lamp, instant start and programmed start). Consumers would achieve negative LCC savings at EL 2 in both the commercial and industrial sectors for all of the scenarios for representative lamps that have the same system power as the baseline lamp. For other lamps at EL 2, consumers would achieve positive LCC savings at EL 2 in the commercial and industrial sectors. Consumers would achieve negative LCC savings at EL 2 in the residential sector.

Event II represents consumers who must replace both a lamp and a ballast. Event III represents consumers who are renovating an existing building or constructing a new building. The results for Events II and III show that consumers would achieve positive LCC savings at EL 1 in the commercial, industrial, and residential sectors for the 2-lamp and 4-lamp instant start scenarios. Consumers would achieve negative LCC savings at EL 1 for the full wattage replacements, but they would achieve positive LCC savings at EL 1 for the reduced wattage replacements in both the commercial and industrial sectors for the 2-lamp programmed start scenarios. Consumers would achieve positive LCC savings at EL 1 in the commercial and industrial sectors at EL 1 for the 4-lamp programmed start scenarios.

The results for Events II and III show that consumers would achieve positive LCC savings at EL 2 in the commercial and industrial sectors for the 2-lamp and 4-lamp instant start scenarios. Consumers would achieve negative LCC savings at EL 2 for the full wattage replacements, but they would achieve positive LCC savings at EL 2 for the reduced wattage replacements in both the commercial and industrial sectors for the 2-lamp programmed start scenarios. Consumers would achieve a range of LCC savings (positive or negative depending on the representative unit) at EL 2 in the commercial and industrial sectors for the 4-lamp programmed start scenarios. Consumers would achieve negative LCC savings at EL 2 in the residential sector except for one representative lamp unit for which consumers would achieve positive LCC savings.

Table 8.5.9 summarizes the range of LCC results for the 4-foot MBP product class in the commercial and industrial sectors.

Table 8.5.11 summarizes the range of LCC results for the 4-foot MBP product class in the residential sector.

Table 8.5.1 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	116.96	134.33	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	33.38	116.96	138.62	-4.29	100	0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.79	98.00	127.98	6.36	0.1	99.9	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.73	116.96	143.88	-9.55	100	0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	23.99	105.12	129.29	5.04	0	100	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	59.99	115.47	158.74	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	76.18	103.28	150.84	7.90	0	100	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.59	96.70	152.58	6.17	0.1	99.9	3.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.53	101.06	153.88	4.87	0.1	99.9	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.79	101.96	152.03	6.72	0	100	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.78	115.47	160.44	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.97	103.28	152.53	7.90	0	100	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.39	96.70	154.27	6.17	0.1	99.9	3.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.33	101.06	155.57	4.87	0.1	99.9	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.58	101.96	153.72	6.72	0	100	2.4

Table 8.5.2 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	84.04	101.41	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	32.69	84.04	105.14	-3.73	100	0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.80	70.42	100.40	1.01	44.2	55.8	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.74	84.04	110.96	-9.55	100	0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	24.00	75.53	99.70	1.71	9	91	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	60.00	82.97	126.43	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	75.49	74.21	121.40	5.04	0	100	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.61	69.48	125.56	0.88	45	55	4.0
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.55	72.61	125.63	0.81	43.3	56.7	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.80	73.26	123.52	2.91	0	100	3.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.79	82.97	128.14	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.29	74.21	123.10	5.04	0	100	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.40	69.48	127.26	0.88	45	55	4.0
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.34	72.61	127.33	0.81	43.3	56.7	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.60	73.26	125.23	2.91	0	100	3.0

Table 8.5.3 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	178.88	196.22	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	31.26	178.88	202.33	-6.11	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.79	150.18	180.13	16.09	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.73	178.88	205.77	-9.55	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	23.99	160.96	185.10	11.12	0.0	100.0	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.19	178.88	234.11	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.27	178.88	240.22	-6.11	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.27	150.40	211.74	22.37	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.80	150.18	218.02	16.09	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.74	178.88	243.66	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.74	150.40	215.18	18.93	0.0	100.0	2.5
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	67.99	160.96	222.99	11.12	0.0	100.0	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.98	178.88	236.52	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	78.06	178.88	242.63	-6.11	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	78.06	150.40	214.15	22.37	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.59	150.18	220.43	16.09	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.53	178.88	246.06	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.53	150.40	217.59	18.93	0.0	100.0	2.5
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.79	160.96	225.40	11.12	0.0	100.0	2.8

Table 8.5.4 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	128.12	145.45	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	30.99	128.12	151.65	-6.20	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.80	107.56	137.51	7.94	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.74	128.12	155.01	-9.55	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	24.00	115.28	139.42	6.03	0.0	100.0	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.20	128.12	183.64	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.00	128.12	189.84	-6.20	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.00	107.72	169.44	14.20	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.81	107.56	175.70	7.94	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.75	128.12	193.19	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.75	107.72	172.80	10.84	0.0	100.0	3.0
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	68.00	115.28	177.61	6.03	0.0	100.0	3.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.99	128.12	186.07	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	77.79	128.12	192.27	-6.20	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	77.79	107.72	171.87	14.20	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.61	107.56	178.13	7.94	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.55	128.12	195.62	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.55	107.72	175.22	10.84	0.0	100.0	3.0
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.80	115.28	180.03	6.03	0.0	100.0	3.4

Table 8.5.5 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.95	225.79	254.11	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	55.06	225.79	261.52	-7.41	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.17	188.99	242.52	11.58	0.2	99.8	3.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	47.05	225.79	273.20	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.56	202.80	244.72	9.39	0.0	100.0	2.9
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.30	223.94	287.56	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	113.40	202.45	273.49	14.07	0.0	100.0	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.51	187.37	276.22	11.35	0.3	99.7	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.39	195.81	278.53	9.03	0.2	99.8	3.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.90	201.09	278.32	9.24	0.0	100.0	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.09	223.94	289.26	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	116.20	202.45	275.18	14.07	0.0	100.0	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.31	187.37	277.91	11.35	0.3	99.7	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.19	195.81	280.23	9.03	0.2	99.8	3.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.70	201.09	280.02	9.24	0.0	100.0	2.9

Table 8.5.6 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.96	162.24	190.55	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	53.92	162.24	197.03	-6.48	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.19	135.80	189.34	1.22	47.4	52.6	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	47.07	162.24	209.66	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.57	145.72	187.64	2.91	16.0	84.0	3.5
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.31	160.90	224.79	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.27	145.47	215.83	8.96	0.0	100.0	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.54	134.63	223.74	1.05	48.2	51.8	4.1
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.42	140.69	223.69	1.11	46.2	53.8	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.92	144.49	221.99	2.81	17.7	82.3	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.11	160.90	226.50	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	115.07	145.47	217.54	8.96	0.0	100.0	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.34	134.63	225.45	1.05	48.2	51.8	4.1
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.21	140.69	225.39	1.11	46.2	53.8	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.72	144.49	223.69	2.81	17.7	82.3	3.5

Table 8.5.7 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.95	354.89	383.16	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.55	354.89	393.58	-10.42	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.17	297.59	351.07	32.08	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.05	354.89	402.25	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.56	319.10	360.97	22.19	0.0	100.0	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.14	354.89	434.98	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.73	339.09	429.60	5.38	0.4	99.6	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.36	297.59	402.90	32.08	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.24	339.09	438.28	-3.29	81.9	18.1	9.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.75	304.62	398.32	36.66	0.0	100.0	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.94	354.89	437.39	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.53	339.09	432.01	5.38	0.4	99.6	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.15	297.59	405.30	32.08	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.03	339.09	440.68	-3.29	81.9	18.1	9.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.54	304.62	400.73	36.66	0.0	100.0	2.0

Table 8.5.8 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.96	254.18	282.44	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.11	254.18	293.01	-10.57	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.19	213.14	266.62	15.81	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.07	254.18	301.54	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.57	228.54	270.41	12.03	0.0	100.0	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.16	254.18	334.67	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.30	242.86	333.93	0.74	44.0	56.0	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.38	213.14	318.86	15.81	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.26	242.86	342.46	-7.79	99.4	0.6	10.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.77	218.18	312.28	22.39	0.0	100.0	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.95	254.18	337.10	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.10	242.86	336.35	0.74	44.0	56.0	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.18	213.14	321.28	15.81	0.0	100.0	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.06	242.86	344.88	-7.79	99.4	0.6	10.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.56	218.18	314.70	22.39	0.0	100.0	2.4

Table 8.5.9 Summary of the LCC Results for a 4-Foot Medium Bipin System, Commercial and Industrial Sectors

Baseline	Efficacy Level	LCC Savings		
		Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
2-Lamp, Instant Start	EL 1	-4.29 to -3.73	5.04 to 7.90	5.04 to 7.90
	EL 2	-9.55 to 6.36	0.81 to 6.72	0.81 to 6.72
2-Lamp, Programmed Start	EL 1	-6.20 to -6.11	-6.20 to 22.37	-6.20 to 22.37
	EL 2	-9.55 to 16.09	-9.55 to 18.93	-9.55 to 18.93
4-Lamp, Instant Start	EL 1	-7.41 to -6.48	8.96 to 14.07	8.96 to 14.07
	EL 2	-19.1 to 11.58	1.05 to 11.35	1.05 to 11.35
4-Lamp, Programmed Start	EL 1	-10.57 to -10.42	0.74 to 5.38	0.74 to 5.38
	EL 2	-19.1 to 32.08	-7.79 to 36.66	-7.79 to 36.66

Table 8.5.10 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	10.48	46.85	57.34	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	11.58	46.85	58.43	-1.09	100	0	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	23.09	39.29	62.38	-5.05	94.8	5.2	17.6
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	20.03	46.85	66.88	-9.55	100	0	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	17.29	42.13	59.41	-2.08	89.8	10.2	15.2
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	52.71	46.85	99.56	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	53.80	44.48	98.28	1.28	1.1	98.9	4.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	65.32	39.29	104.61	-5.05	94.8	5.2	17.6
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	62.26	44.48	106.73	-7.17	100	0	42.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	59.51	39.99	99.50	0.06	49	51	10.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.51	46.85	102.36	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.60	44.48	101.08	1.28	1.1	98.9	4.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	68.11	39.29	107.40	-5.05	94.8	5.2	17.6
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	65.05	44.48	109.53	-7.17	100	0	42.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	62.31	39.99	102.30	0.06	49	51	10.5

Table 8.5.11 Summary of the LCC Results for a 4-Foot Medium Bipin System, Residential Sector

Baseline	Efficacy Level	LCC Savings		
		Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
2-Lamp, Instant Start	EL 1	-1.09	1.28	1.28
	EL 2	-9.55 to -2.08	-7.17 to 0.06	-7.17 to 0.06

8.5.1.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

For the 4-foot T5 MiniBP HO $\leq 4,500$ K product class in the commercial and industrial sectors, DOE analyzes one baseline lamp, a 54 W T5. For the baseline lamp, DOE analyzes multiple lamp substitutions with each lamp substitution corresponding to the EL requirements.

Table 8.5.12 presents the results for a 4-foot T5 MiniBP HO baseline system operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.9 years, and average weighted lamp prices.

Table 8.5.13 presents the results for a 4-foot T5 MiniBP HO baseline system operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.2 years, and average weighted lamp prices.

The results for Event I (lamp failure) show that consumers would achieve positive LCC savings at EL 1 in both the commercial and industrial sectors, except for one representative lamp unit in both sectors for which consumers would achieve negative LCC savings.

Event II represents consumers who must replace both a lamp and a ballast. Event III represents consumers who are renovating an existing building or constructing a new building. The results for Events II and III show that consumers would achieve positive LCC savings at EL 1 in both the commercial and industrial sectors for the lamp-and-ballast replacement events, except for one representative lamp unit in both sectors for which consumers would achieve negative LCC savings.

Table 8.5.14 summarizes the range of LCC results for the 4-foot T5 MiniBP HO product class.

Table 8.5.12 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.57	252.42	271.17	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.59	252.42	279.19	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.51	230.52	256.17	15.00	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	35.42	221.38	252.52	18.66	0.0	100.0	2.7
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.68	252.42	304.72	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.70	252.42	312.73	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.62	230.52	289.72	15.00	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	89.53	221.38	286.06	18.66	0.0	100.0	2.7
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.47	252.42	306.45	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.49	252.42	314.47	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.41	230.52	291.45	15.00	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	92.32	221.38	287.79	18.66	0.0	100.0	2.7

Table 8.5.13 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.58	181.10	199.85	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.60	181.10	207.87	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.52	165.38	191.12	8.73	0.0	100.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	35.43	158.83	190.02	9.83	0.0	100.0	3.3
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.69	181.10	233.62	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.72	181.10	241.65	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.64	165.38	224.89	8.73	0.0	100.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	89.55	158.83	223.79	9.83	0.0	100.0	3.3
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.49	181.10	235.37	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.51	181.10	243.39	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.43	165.38	226.64	8.73	0.0	100.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	92.35	158.83	225.54	9.83	0.0	100.0	3.3

Table 8.5.14 Summary of the LCC Results for a 4-Foot T5 MiniBP HO System

Efficacy Level	LCC Savings		
	Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
EL 1	-8.02 to 18.66	-8.02 to 18.66	-8.02 to 18.66

8.5.1.3 Product Class: 4-foot T5 miniature bipin standard output $\leq 4,500$ K

For the 4-foot T5 MiniBP SO $\leq 4,500$ K product class in the commercial and industrial sectors, DOE analyzes one baseline lamp, a 28 W T5. For the baseline lamp, DOE analyzes multiple lamp substitutions with each lamp substitution corresponding to the EL requirements.

Table 8.5.15 presents the results for a 4-foot T5 MiniBP SO baseline system operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 7.1 years, and average weighted lamp prices.

Table 8.5.16 presents the results for a 4-foot T5 MiniBP SO baseline system operating in the industrial sector. Key inputs consist of using *AEO 2012* reference case electricity prices, an analysis period of 6.3 years, and average weighted lamp prices.

The results for Event I (lamp failure) show that consumers would achieve negative LCC savings for the lamp at EL 1 in both the commercial and industrial sectors. Consumers would achieve negative LCC savings at EL 2 in both the commercial and industrial sectors, except for one representative lamp unit in the industrial sector for which consumers would achieve positive LCC savings and two representative lamp units in the commercial sector for which consumers would achieve positive LCC savings.

Event II represents consumers who must replace both a lamp and a ballast. Event III represents consumers who are renovating an existing building or constructing a new building. The results for Events II and III show that consumers would achieve positive LCC savings for the lamp at EL 1 in both the commercial and industrial sectors for the lamp-and-ballast replacement events. Consumers would achieve positive LCC savings at EL 2 in both the commercial and industrial sectors for the lamp-and-ballast replacement events.

Table 8.5.17 summarizes the range of LCC results for the 4-foot T5 MiniBP SO product class.

Table 8.5.15 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	15.30	152.84	168.31	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	104.3	27.8 W T5 & 1 BF Prog	19.17	152.84	172.18	-3.87	100.0	0.0	NER
		EL 2	109.7	27.8 W T5 & 1 BF Prog	21.52	152.84	174.54	-6.22	100.0	0.0	NER
		EL 2	111.5	26 W T5 & 1 BF Prog	24.67	143.23	168.07	0.25	57.9	42.1	5.7
		EL 2	116.0	25 W T5 & 1 BF Prog	27.41	137.88	162.64	5.68	0.2	99.8	4.8
Event II: Ballast Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	68.19	152.84	205.74	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	72.06	134.13	190.90	14.84	0.0	100.0	1.2
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	74.41	134.13	193.25	12.49	0.0	100.0	2.0
		EL 2	111.5	26 W T5 & 0.85 BF Prog	77.56	125.79	188.05	17.69	0.0	100.0	2.0
		EL 2	116.0	25 W T5 & 0.85 BF Prog	80.30	121.15	183.32	22.42	0.0	100.0	2.2
Event III: New Construction and Renovation	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	70.99	152.84	207.72	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	74.86	134.13	192.88	14.84	0.0	100.0	1.2
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	77.21	134.13	195.23	12.49	0.0	100.0	2.0
		EL 2	111.5	26 W T5 & 0.85 BF Prog	80.35	125.79	190.03	17.69	0.0	100.0	2.0
		EL 2	116.0	25 W T5 & 0.85 BF Prog	83.10	121.15	185.30	22.42	0.0	100.0	2.2

Table 8.5.16 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	15.30	109.55	125.02	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	104.3	27.8 W T5 & 1 BF Prog	19.17	109.55	128.89	-3.87	100.0	0.0	NER
		EL 2	109.7	27.8 W T5 & 1 BF Prog	21.53	109.55	131.24	-6.22	100.0	0.0	NER
		EL 2	111.5	26 W T5 & 1 BF Prog	24.67	102.66	127.50	-2.48	95.6	4.4	6.9
		EL 2	116.0	25 W T5 & 1 BF Prog	27.42	98.83	123.65	1.37	28.8	71.2	5.8
Event II: Ballast Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	68.21	109.55	162.81	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	72.08	96.14	153.27	9.54	0.0	100.0	1.5
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	74.43	96.14	155.62	7.18	0.0	100.0	2.4
		EL 2	111.5	26 W T5 & 0.85 BF Prog	77.58	90.16	152.79	10.02	0.0	100.0	2.5
		EL 2	116.0	25 W T5 & 0.85 BF Prog	80.32	86.83	149.44	13.37	0.0	100.0	2.7
Event III: New Construction and Renovation	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	71.00	109.55	164.81	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	74.87	96.14	155.27	9.54	0.0	100.0	1.5
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	77.23	96.14	157.62	7.18	0.0	100.0	2.4
		EL 2	111.5	26 W T5 & 0.85 BF Prog	80.37	90.16	154.79	10.02	0.0	100.0	2.5
		EL 2	116.0	25 W T5 & 0.85 BF Prog	83.12	86.83	151.44	13.37	0.0	100.0	2.7

Table 8.5.17 Summary of the LCC Results for a 4-Foot T5 MiniBP SO System

Efficacy Level	LCC Savings		
	Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
EL 1	-3.87	9.54 to 14.84	9.54 to 14.84
EL 2	-6.22 to 5.68	7.18 to 22.42	7.18 to 22.42

8.5.1.4 Product Class: 8-Foot single pin slimline $\leq 4,500$ K

For the 8-foot SP slimline $\leq 4,500$ K product class in the commercial and industrial sectors, DOE analyzes one baseline lamp, a 59 W T8. For the baseline lamp, DOE analyzes multiple lamp substitutions with each lamp substitution corresponding to the EL requirements.

Table 8.5.18 presents the results for an 8-foot SP slimline baseline system operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 5.6 years, and average weighted lamp prices.

Table 8.5.19 presents the results for an 8-foot SP slimline baseline system operating in the industrial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 4.9 years, and average weighted lamp prices.

The results for Event I (lamp failure) show that consumers would achieve negative LCC savings for the lamp at EL 1 in both the commercial and industrial sectors. Consumers would achieve negative LCC savings at EL 2 in both the commercial and industrial sectors, except for one representative lamp unit in the commercial sector for which consumers would achieve positive LCC savings.

Event II represents consumers who must replace both a lamp and a ballast. Event III represents consumers who are renovating an existing building or constructing a new building. The results for Events II and III show that consumers would achieve positive LCC savings for the lamp at EL 1 in both the commercial and industrial sectors for the lamp-and-ballast replacement events. Consumers would achieve positive LCC savings at EL 2 in both the commercial and industrial sectors for the lamp-and-ballast replacement events, except for one representative lamp unit in the industrial sector for which consumers would achieve negative LCC savings.

Table 8.5.20 summarizes the range of LCC results for the 8-foot SP slimline product class.

Table 8.5.18 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.72	219.51	246.59	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.40	219.51	249.27	-2.68	100.0	0.0	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.52	219.51	254.39	-7.80	100.0	0.0	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.51	208.16	252.02	-5.43	96.1	3.9	7.1
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.87	193.01	244.23	2.36	44.6	55.4	4.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.46	216.15	288.57	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.14	193.01	268.11	20.46	0.0	100.0	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.25	193.01	273.23	15.34	0.0	100.0	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.24	183.01	272.22	16.35	0.0	100.0	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.60	189.96	286.53	2.05	47.6	52.4	4.4
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.25	216.15	290.24	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.93	193.01	269.78	20.46	0.0	100.0	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.05	193.01	274.90	15.34	0.0	100.0	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.04	183.01	273.89	16.35	0.0	100.0	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.40	189.96	288.20	2.05	47.6	52.4	4.4

Table 8.5.19 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.73	157.75	184.83	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.41	157.75	187.51	-2.68	100.0	0.0	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.53	157.75	192.63	-7.80	100.0	0.0	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.52	149.59	193.46	-8.63	100.0	0.0	8.6
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.88	138.70	189.94	-5.11	93.3	6.7	5.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.47	155.33	228.10	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.15	138.70	214.15	13.95	0.0	100.0	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.27	138.70	219.27	8.83	0.0	100.0	2.0
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.26	131.52	221.08	7.02	0.0	100.0	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.62	136.51	233.43	-5.33	93.8	6.2	5.3
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.27	155.33	229.78	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.95	138.70	215.83	13.95	0.0	100.0	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.07	138.70	220.95	8.83	0.0	100.0	2.0
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.06	131.52	222.76	7.02	0.0	100.0	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.42	136.51	235.11	-5.33	93.8	6.2	5.3

Table 8.5.20 Summary of the LCC Results for an 8-Foot SP Slimline System

Efficacy Level	LCC Savings		
	Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
EL 1	-2.68	13.95 to 20.46	13.95 to 20.46
EL 2	-8.63 to 2.36	-5.33 to 16.35	-5.33 to 16.35

8.5.1.5 Product Class: 8-foot recessed double contact HO $\leq$ 4,500 K

For the 8-foot RDC HO $\leq$ 4,500 K product class in the commercial and industrial sectors, DOE analyzes one baseline lamp, an 86 W T8.

Table 8.5.21 presents the results for an 8-foot RDC HO baseline system operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 4.2 years, and average weighted lamp prices.

Table 8.5.22 presents the results for an 8-foot RDC HO baseline system operating in the industrial sector. Key inputs consist of using *AEO 2012* reference case electricity prices, an analysis period of 3.7 years, and average weighted lamp prices.

The results for Event I (lamp failure) show that consumers would face negative LCC savings in both the commercial and industrial sectors because there is an installed cost increase but no change in energy consumption.

Event II represents consumers who must replace both a lamp and a ballast. Event III represents consumers who are renovating an existing building or constructing a new building. The results for Events II and III show that consumers would also achieve negative LCC savings in both the commercial and industrial sectors for the lamp-and-ballast replacement events since there is an installed cost increase but no change in energy consumption.

Table 8.5.23 summarizes the range of LCC results for the 8-foot RDC HO product class.

Table 8.5.21 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	238.37	263.21	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.00	238.37	272.77	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.21	238.37	279.97	-16.76	100.0	0.0	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.33	238.37	298.54	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.89	238.37	308.10	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.09	238.37	315.30	-16.76	100.0	0.0	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.13	238.37	299.84	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.68	238.37	309.40	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.89	238.37	316.60	-16.76	100.0	0.0	NER

Table 8.5.22 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	171.55	196.38	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.01	171.55	205.94	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.22	171.55	213.15	-16.77	100.0	0.0	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.34	171.55	233.59	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.90	171.55	243.15	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.11	171.55	250.36	-16.77	100.0	0.0	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.14	171.55	234.96	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.70	171.55	244.52	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.91	171.55	251.73	-16.77	100.0	0.0	NER

Table 8.5.23 Summary of the LCC Results for an 8-Foot RDC HO System

Efficacy Level	LCC Savings		
	Event I: Lamp Failure	Event II: Ballast Failure	Event III: New Construction and Renovation
EL 1	-9.56	-9.56	-9.56
EL 2	-16.77 to -16.76	-16.77 to -16.76	-16.77 to -16.76

8.5.2 Results for Incandescent Reflector Lamps

For the standard spectrum, diameter greater than 2.5 inches, and voltage less than 125 V product class in the commercial and residential sectors, DOE analyzes one baseline lamp, a 60 W 1,500-hour improved halogen lamp.

Table 8.5.24 presents the results for a 55 W PAR38 2,500-hour halogen infrared reflector (HIR) EL 1 representative lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 0.3 years, and average weighted lamp prices.

Table 8.5.25 presents the results for a 55 W PAR38 2,500-hour HIR EL 1 representative lamp operating in the residential sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 2.0 years, and average weighted lamp prices.

Table 8.5.26 presents the results for a 55 W PAR38 4,200-hour improved HIR EL 1 representative lamp operating in the commercial sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 0.3 years, and average weighted lamp prices.

Table 8.5.27 presents the results for a 55 W PAR38 4,200-hour improved HIR EL 1 representative lamp operating in the residential sector. Key inputs consist of using *AEO 2013* reference case electricity prices, an analysis period of 2.0 years, and average weighted lamp prices.

The results for Event I (lamp failure) and Event III (new construction and renovation) show that consumers would face positive LCC savings for both EL 1 representative lamps for both the commercial and residential sectors.

Table 8.5.28 summarizes the range of LCC results for the standard spectrum, diameter greater than 2.5 inches, and voltage less than 125 V product class in the commercial and residential sectors.

Table 8.5.24 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR EL 1 Representative Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.06	19.58	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	13.07	8.30	16.14	3.44	0.0	100.0	3.2

Table 8.5.25 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR EL 1 Representative Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.36	19.75	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	9.49	17.10	2.65	0.0	100.0	5.4

Table 8.5.26 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR EL 1 Representative Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.06	19.58	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	14.94	8.30	13.64	5.94	0	100	5.6

Table 8.5.27 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR EL 1 Representative Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life-Cycle Cost			Life-Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.36	19.75	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	9.49	15.26	4.49	0	100	9.4

Table 8.5.28 Summary of the LCC Results for Standard Spectrum, Diameter Greater Than 2.5 inches, and Voltage Less Than 125 V Product Class

EL 1 Representative Unit	Efficacy Level	LCC Savings for Event I: Lamp Failure or Event III: New Construction and Renovation
2500 Hour 55W HIR	EL 1	2.65 to 3.44
4200 Hour 55W Improved HIR	EL 1	4.49 to 5.94

8.6 DETAILED RESULTS AND SENSITIVITY RUNS

DOE presents more detailed results and sensitivity runs from the LCC analysis in appendix 8B of this NOPR TSD. These results include Monte Carlo probability distributions, price sensitivity scenarios, electricity price trend scenarios, and lighting controls scenarios for GSFLs and IRLs. In addition, results are provided for rare earth scenarios for GSFLs and operating hour sensitivity scenarios and shortened lifetime scenarios for IRLs.

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CHAPTER 9. LIFE-CYCLE COST SUBGROUP ANALYSIS

9.1 INTRODUCTION

Chapter 8 of this NOPR TSD describes the life-cycle cost (LCC) and payback period (PBP) analysis that examines impacts of energy conservation standards on the U.S. population. In analyzing the potential impact of new or amended standards on consumers, DOE further evaluates the impact on identifiable groups of consumers (i.e., consumer subgroups) that may be disproportionately affected by a national standard level. The LCC subgroup analysis evaluates impacts by analyzing the LCC and PBPs for subgroups of households or commercial and industrial consumers. For general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs), DOE identified two consumer subgroups that warranted further study: low-income consumers and institutions that serve low-income populations. The analysis determines whether these groups of consumers would be adversely affected by any of the trial standard levels (TSLs).

DOE determined the impact on consumer subgroups for GSFLs and IRLs using the LCC spreadsheet model, which allows for the examination of particular consumer subgroups. The LCC analysis for the general population (described in chapter 8 of this NOPR TSD) focuses on consumers that use GSFLs and IRLs. DOE has the ability to use the LCC spreadsheet model to analyze the LCC for any subgroup by sampling only the data that apply to that subgroup. (Chapter 8 of this NOPR TSD explains in detail the inputs to the model used in determining LCC and PBPs.)

This chapter describes the subgroups analyzed in further detail and gives the results of the LCC and PBP analyses for both GSFLs and IRLs. Section 9.2 discusses the definitions and inputs used for the two subgroups while section 9.3 gives the LCC and PBP results for the two subgroups.

9.2 SUBGROUP DEFINITIONS AND INPUTS TO THE SUBGROUP ANALYSIS

9.2.1 Low-Income Consumers

As discussed in chapters 6 and 8 of this NOPR TSD, DOE used Energy Information Administration's (EIA's) 2009 Residential Energy Consumption Survey (RECS)¹ to calculate the probabilities of a lamp type within each building type and division or large state, which are used as inputs to the operating hours, electricity price, and sales tax calculations. To analyze low-income consumers, DOE filtered the RECS data such that it only included data for consumers below the poverty line. Using this data, DOE developed the inputs to the LCC and PBP analysis for this consumer subgroup.

9.2.2 Institutions That Serve Low-Income Populations

DOE expects that the majority of organizations serving low-income populations are small non-profit groups. For this reason, DOE chose a subgroup scenario with a discount rate of 9.6 percent, which is 4.5 percent higher than the average discount rate of 5.1 percent for the commercial sector used in the primary LCC analysis. This discount rate is based on the development of the discount rate for small business subgroups.

The Small Business Administration (SBA) defines a small business by its annual receipts or its number of employees. To calculate discount rates for small companies that purchase IRLs or GSFLs, DOE used the same methodology as for the general population as presented in chapter 8 of this NOPR TSD.^a Although the methodology is appropriate, the capital asset pricing model (CAPM) described in chapter 8 of this NOPR TSD for the general population underestimates the cost of capital for small companies. In CAPM, the risk premium β is used to account for the higher returns associated with greater risk. However, for small companies, particularly very small companies, historic returns have been significantly higher than the CAPM equation predicts. This additional return can be accounted for by adding a size premium to the cost of equity for small firms:

$$k_e = R_f + (\beta \times ERP) + S$$

Eq. 9.1

Where:

- k_e = cost of equity,
- R_f = expected return on risk-free assets,
- β = risk coefficient of the firm,
- ERP = equity risk premium, and
- S = size premium.

DOE obtained size premium data from Ibbotson Associates' *Stocks, Bonds, Bills, and Inflation 2009 Yearbook*.² For the period of 1926–2008, the average size premium for the smallest companies in all industries is 5.8 percent, implying that on average, historic performance of small companies has been 5.8 percent higher than the CAPM estimate of the small company cost of equity.^b

DOE calculated the real weighted average cost of capital (as described in chapter 8 of this NOPR TSD) using the cost of equity including a size premium for small companies instead of the CAPM cost of equity. DOE used this cost of equity calculation to estimate that in industries that purchase GSFLs or IRLs, small companies have an average discount rate 4.5 percent higher than the industry average.

In chapter 8 of this NOPR TSD, DOE estimated the average discount rate for commercial consumers to be 5.1 percent. Applying the additional small capitalization (small cap) discount rate premium of 4.5 percent presented above to these discount rates for businesses that purchase GSFLs or IRLs, the average discount rate for small commercial companies is approximately 9.6 percent. Because DOE expects that the majority of institutions serving low income populations are small companies, DOE is using the discount rate of 9.6 percent for the LCC subgroup analysis of institutions serving low income populations as a modification to the commercial

^a DOE assumed that small businesses as a whole are a reasonable approximation for small businesses that use GSFLs or IRLs.

^b In this calculation, small companies are defined as companies with market capitalization of less than or equal to \$128.78 million, the Ibbotson Associates' definition of Decile 10 companies.

sector primary LCC analysis. DOE kept all other aspects of the subgroup LCC analysis the same as in the commercial sector primary LCC analysis.

9.3 LCC SUBGROUP RESULTS

The following tables present the results of the LCC subgroup analyses for low-income consumers and institutions that serve low-income populations. The subgroup analysis is based on the primary LCC analysis described in chapter 8 of this NOPR TSD, with modifications described above in section 9.2 of this chapter. For information on the acronyms used in the summary tables, see chapter 8 of this NOPR TSD.

9.3.1 Low-Income Consumers

For low-income consumers, DOE used filtered RECS that only included data for consumers below the poverty line to develop inputs to the LCC and PBP analysis. Positive primary LCC results generally remained positive for this subgroup while negative primary LCC results remained negative for this subgroup. The payback periods for this subgroup are similar to the payback periods in the residential sector LCC analysis.

9.3.1.1 GSFL Product Class: 4-foot MBP $\leq$ 4,500 K

The results for the LCC and PBP subgroup analyses for low-income consumers are shown in Table 9.3.1 for GSFLs. In general, LCC savings and payback periods are similar in the primary residential sector and for low-income residential consumers. LCC results that were positive in the primary LCC analysis remained positive for this subgroup; the same occurred for negative primary LCC results. LCC savings for low-income consumers change by \$0.00 to -\$0.02 when compared to the primary residential sector analysis. PBPs for low-income consumers change by 0.0 to 0.1 years when compared to the primary residential sector analysis.

Table 9.3.1 LCC and PBP Subgroup Results for Low-Income Consumers for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	10.49	46.83	57.32	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	11.59	46.83	58.42	-1.09	100	0	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	23.11	39.27	62.38	-5.06	94.9	5.1	17.6
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	20.05	46.83	66.88	-9.56	100	0	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	17.30	42.11	59.41	-2.09	90.3	9.7	15.2
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	52.73	46.83	99.56	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	53.82	44.45	98.28	1.28	1.1	98.9	4.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	65.35	39.27	104.62	-5.06	94.9	5.1	17.6
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	62.29	44.45	106.74	-7.18	100	0	42.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	59.54	39.97	99.51	0.05	49.9	50.1	10.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.53	46.83	102.35	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.62	44.45	101.07	1.28	1.1	98.9	4.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	68.14	39.27	107.41	-5.06	94.9	5.1	17.6
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	65.08	44.45	109.54	-7.18	100	0	42.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	62.33	39.97	102.30	0.05	49.9	50.1	10.5

9.3.1.2 Incandescent Reflector Lamps

The results for the LCC and PBP subgroup analyses for low-income consumers are shown in Table 9.3.2 through Table 9.3.3 for IRLs. In general, LCC savings and payback periods are similar in the primary residential sector and for low-income residential consumers. LCC results that were positive in the primary LCC analysis remained positive for this subgroup; the same occurred for negative primary LCC results. LCC savings for low-income consumers change by -\$0.01 when compared to the primary residential sector analysis. PBPs for low-income consumers change by 0.1 to 0.2 years when compared to the primary residential sector analysis.

Table 9.3.2 LCC and PBP Subgroup Results for Low-Income Consumers for a 55 W PAR38 2,500 Hour HIR EL 1 Representative Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60 W, 1,500 hrs, Improved Halogen	9.40	10.21	19.62	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55 W, 2,500 hrs, HIR	11.95	9.36	16.98	2.64	0.0	100.0	5.5

Table 9.3.3 LCC and PBP Subgroup Results for Low-Income Consumers for a 55 W PAR38 4,200 Hour Improved HIR EL 1 Representative Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60 W, 1,500 hrs, Improved Halogen	9.40	10.21	19.62	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55 W, 4,200 hrs, Improved HIR	13.82	9.36	15.13	4.48	0	100	9.5

9.3.2 Institutions That Serve Low-Income Populations

Because DOE assumed that the majority of institutions that serve low-income populations are small non-profit organizations, DOE used a 9.6 percent discount rate, which is higher than the 5.1 percent used for the primary commercial sector analysis. As a result of the higher discount rate, institutions that serve low-income populations generally experience lower LCC savings than the rest of the commercial sector. Positive primary LCC results generally remained positive for this subgroup while negative primary LCC results remained negative for this subgroup, except in specific instances described below. The payback periods for this subgroup are identical to the payback periods in the commercial sector LCC analysis because DOE computes simple PBPs, which do not take into account discounting; thus, changes in discount rates do not change the PBPs.

9.3.2.1 GSFL Product Class: 4-foot MBP $\leq$ 4,500 K

Table 9.3.4 through Table 9.3.7 present the results for the 4-foot MBP systems operating in institutions that serve low-income populations. LCC savings that are positive in the primary commercial sector analysis remain positive for this subgroup. LCC savings that are negative in the primary commercial sector analysis remain negative for this subgroup. LCC savings in institutions that serve low-income populations change by \$1.30 to -\$10.40 when compared to the primary commercial sector analysis.

Table 9.3.4 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	102.28	119.60	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	31.03	102.28	124.21	-4.61	100	0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.79	85.69	115.63	3.97	4.2	95.8	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.73	102.28	129.15	-9.55	100	0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	23.99	91.92	116.05	3.56	0	100	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	59.99	100.97	147.99	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	73.83	90.31	141.93	6.05	0	100	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.59	84.55	144.18	3.81	6.6	93.4	3.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.53	88.37	144.93	3.06	3.6	96.4	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.79	89.15	142.97	5.02	0	100	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.78	100.97	149.93	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	76.62	90.31	143.87	6.05	0	100	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.39	84.55	146.12	3.81	6.6	93.4	3.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.33	88.37	146.87	3.06	3.6	96.4	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.58	89.15	144.91	5.02	0	100	2.4

Table 9.3.5 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy <i>lm/W</i>	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period <i>years</i>
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
					2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	146.45	163.74	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	27.94	146.45	169.05	-5.31	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.79	122.95	152.85	10.89	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.73	146.45	173.29	-9.55	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	23.99	131.77	155.87	7.87	0.0	100.0	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.19	146.45	203.56	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	71.94	146.45	208.87	-5.31	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	71.94	123.13	185.56	18.01	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.80	122.95	192.68	10.89	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.74	146.45	213.11	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.74	123.13	189.80	13.77	0.0	100.0	2.5
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	67.99	131.77	195.69	7.87	0.0	100.0	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.98	146.45	206.09	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	74.73	146.45	211.40	-5.31	100.0	0.0	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	74.73	123.13	188.09	18.01	0.0	100.0	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.59	122.95	195.21	10.89	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.53	146.45	215.64	-9.55	100.0	0.0	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.53	123.13	192.33	13.77	0.0	100.0	2.5
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.79	131.77	198.22	7.87	0.0	100.0	2.8

Table 9.3.6 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.95	197.44	225.67	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	51.18	197.44	233.62	-7.95	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.17	165.26	218.70	6.96	8.8	91.2	3.3
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	47.05	197.44	244.76	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.56	177.33	219.17	6.50	0.1	99.9	2.9
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.30	195.81	264.52	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	109.52	177.03	253.68	10.84	0.0	100.0	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.51	163.84	257.76	6.76	9.4	90.6	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.39	171.22	259.02	5.50	7.9	92.1	3.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.90	175.84	258.15	6.37	0.2	99.8	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.09	195.81	266.46	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.32	177.03	255.62	10.84	0.0	100.0	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.31	163.84	259.70	6.76	9.4	90.6	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.19	171.22	260.96	5.50	7.9	92.1	3.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.70	175.84	260.09	6.37	0.2	99.8	2.9

Table 9.3.7 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.95	290.55	318.71	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	46.06	290.55	327.82	-9.11	100.0	0.0	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.17	243.64	297.02	21.70	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.05	290.55	337.81	-19.10	100.0	0.0	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.56	261.25	303.02	15.70	0.0	100.0	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.14	290.55	373.19	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	106.25	277.61	369.36	3.83	4.6	95.4	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.36	243.64	351.49	21.70	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.24	277.61	379.35	-6.16	96.0	4.0	9.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.75	249.39	345.64	27.55	0.0	100.0	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.94	290.55	375.72	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	109.04	277.61	371.89	3.83	4.6	95.4	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.15	243.64	354.02	21.70	0.0	100.0	3.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.03	277.61	381.88	-6.16	96.0	4.0	9.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.54	249.39	348.17	27.55	0.0	100.0	2.0

9.3.2.2 GSFL Product Class: 4-foot T5 MiniBP HO $\leq 4,500$ K

Table 9.3.8 presents the results for a 4-foot T5 MiniBP HO system operating in institutions that serve low-income populations. LCC savings that are positive in the primary commercial sector analysis remain positive for this subgroup. LCC savings that are negative in the primary commercial sector analysis remain negative for this subgroup. LCC savings in institutions that serve low-income populations are reduced by \$0.00 to \$5.01 when compared to the primary commercial sector analysis.

Table 9.3.8 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.57	219.84	238.55	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.59	219.84	246.57	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.51	200.77	227.96	10.60	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	35.42	192.81	224.90	13.65	0.0	100.0	2.7
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.68	219.84	276.70	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.70	219.84	284.72	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.62	200.77	266.11	10.60	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	89.53	192.81	263.05	13.65	0.0	100.0	2.7
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.47	219.84	278.68	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.49	219.84	286.69	-8.02	100.0	0.0	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.41	200.77	268.08	10.60	0.0	100.0	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	92.32	192.81	265.03	13.65	0.0	100.0	2.7

9.3.2.3 GSFL Product Class: 4-foot T5 MiniBP SO $\leq 4,500$ K

Table 9.3.9 presents the results for a 4-foot T5 MiniBP SO system operating in institutions that serve low-income populations. LCC savings that are positive in the primary commercial sector analysis remain positive for this subgroup, except for the EL 2 26 W T5 replacement system for Event I (lamp failure), for which savings shifted from positive to negative. LCC savings that are negative in the primary commercial sector analysis remain negative for this subgroup. LCC savings in institutions that serve low-income populations are reduced by \$0.00 to \$5.40 when compared to the primary commercial sector analysis.

Table 9.3.9 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	15.30	130.31	145.74	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	104.3	27.8 W T5 & 1 BF Prog	19.17	130.31	149.61	-3.87	100.0	0.0	NER
		EL 2	109.7	27.8 W T5 & 1 BF Prog	21.52	130.31	151.96	-6.22	100.0	0.0	NER
		EL 2	111.5	26 W T5 & 1 BF Prog	24.67	122.12	146.91	-1.17	75.3	24.7	5.7
		EL 2	116.0	25 W T5 & 1 BF Prog	27.41	117.56	142.99	2.75	11.4	88.6	4.8
Event II: Ballast Failure	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	68.19	130.31	187.13	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	72.06	114.36	175.05	12.08	0.0	100.0	1.2
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	74.41	114.36	177.40	9.73	0.0	100.0	2.0
		EL 2	111.5	26 W T5 & 0.85 BF Prog	77.56	107.25	173.43	13.70	0.0	100.0	2.0
		EL 2	116.0	25 W T5 & 0.85 BF Prog	80.30	103.29	170.11	17.02	0.0	100.0	2.2
Event III: New Construction and Renovation	Baseline	Baseline	94.6	27.8 W T5 & 1 BF Prog	70.99	130.31	189.32	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	104.3	27.8 W T5 & 0.85 BF Prog	74.86	114.36	177.23	12.08	0.0	100.0	1.2
		EL 2	109.7	27.8 W T5 & 0.85 BF Prog	77.21	114.36	179.59	9.73	0.0	100.0	2.0
		EL 2	111.5	26 W T5 & 0.85 BF Prog	80.35	107.25	175.62	13.70	0.0	100.0	2.0
		EL 2	116.0	25 W T5 & 0.85 BF Prog	83.10	103.29	172.30	17.02	0.0	100.0	2.2

9.3.2.4 GSFL Product Class: 8-foot SP Slimline ≤ 4,500 K

Table 9.3.10 presents the results for the 8-foot SP slimline systems operating in institutions that serve low-income populations. LCC savings that are positive in the primary commercial sector analysis remain positive for this subgroup, except for the EL 2 50 W T8 replacement system for all events, for which savings shifted from positive to negative. LCC savings that are negative in the primary commercial sector analysis remain negative for this subgroup. LCC savings in institutions that serve low-income populations are reduced by \$0.00 to \$4.11 when compared to the primary commercial sector analysis.

Table 9.3.10 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.72	192.30	219.30	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.40	192.30	221.98	-2.68	100.0	0.0	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.52	192.30	227.10	-7.80	100.0	0.0	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.51	182.36	226.14	-6.84	99.6	0.4	7.1
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.87	169.08	220.23	-0.92	67.7	32.3	4.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.46	189.36	268.51	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.14	169.09	250.92	17.59	0.0	100.0	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.25	169.09	256.04	12.47	0.0	100.0	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.24	160.33	256.27	12.24	0.0	100.0	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.60	166.42	269.71	-1.20	68.7	31.3	4.4
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.25	189.36	270.44	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.93	169.09	252.84	17.59	0.0	100.0	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.05	169.09	257.96	12.47	0.0	100.0	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.04	160.33	258.19	12.24	0.0	100.0	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.40	166.42	271.64	-1.20	68.7	31.3	4.4

9.3.2.5 GSFL Product Class: 8-foot RDC HO $\leq 4,500$ K

Table 9.3.11 presents the results for the 8-foot RDC HO systems operating in institutions that serve low-income populations. LCC savings that are negative in the primary commercial sector analysis remain negative for this subgroup. LCC savings in institutions that serve low-income populations are equal to the primary LCC savings for this product class.

Table 9.3.11 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	214.21	238.99	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.00	214.21	248.54	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.21	214.21	255.75	-16.76	100.0	0.0	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.33	214.21	280.62	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.89	214.21	290.18	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.09	214.21	297.38	-16.76	100.0	0.0	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.13	214.21	282.16	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.68	214.21	291.71	-9.56	100.0	0.0	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.89	214.21	298.92	-16.76	100.0	0.0	NER

9.3.2.6 Incandescent Reflector Lamps

Table 9.3.12 through Table 9.3.13 present the results for IRLs operating in institutions that serve low income populations. LCC savings that are positive in the primary commercial sector analysis remain positive for this subgroup. LCC savings are reduced by \$0.03 for institutions that serve low-income populations when compared to the primary commercial sector analysis.

Table 9.3.12 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 55 W PAR38 2,500 Hour HIR EL 1 Representative Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy <i>lm/W</i>	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period <i>years</i>
					Installed Cost <i>2012\$</i>	Discounted Operating Cost <i>2012\$</i>	LCC <i>2012\$</i>	LCC Savings <i>2012\$</i>	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60 W, 1,500 hrs, Improved Halogen	10.52	8.68	19.21	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55 W, 2,500 hrs, HIR	13.07	7.96	15.80	3.41	0.0	100.0	3.2

Table 9.3.13 LCC and PBP Subgroup Results for Institutions Serving Low Income Populations for a 55 W PAR38 4,200 Hour Improved HIR EL 1 Representative Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience		
									Net Cost	Net Benefit	
			lm/W		2012\$	2012\$	2012\$	2012\$			years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60 W, 1,500 hrs, Improved Halogen	10.52	8.68	19.21	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55 W, 4,200 hrs, Improved HIR	14.94	7.96	13.30	5.91	0.0	100.0	5.6

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² Ibbotsons Associates. Stocks, Bonds, Bills, and Inflation 2009 Yearbook, 2009. Chicago, IL.

CHAPTER 10. TRIAL STANDARD LEVELS

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CHAPTER 10. TRIAL STANDARD LEVELS

10.1 INTRODUCTION

The U.S. Department of Energy (DOE) generated national energy savings (NES) and net present value (NPV) results based on trial standard levels (TSLs). The TSLs designate an efficacy level (EL) for each product class. ELs are developed for each product class in the engineering analysis. In this chapter, DOE is only presenting the TSLs of the product classes that DOE analyzed directly (the “representative product classes”).

10.2 GENERAL SERVICE FLUORESCENT LAMPS

10.2.1 Representative Product Classes

In chapter 3 of this notice of proposed rulemaking (NOPR) technical support document (TSD), DOE identifies twelve product classes for general service fluorescent lamps (GSFLs). Rather than analyze all product classes, DOE selected certain product classes as “representative” to analyze in further detail. The following lamps with a color correlated temperature (CCT) less than or equal to 4,500 kelvin (K) compose the five representative product classes for GSFLs: (1) 4-foot medium bipin (MBP); (2) 8-foot single pin (SP) slimline; (3) 8-foot recessed double contact (RDC) high output (HO) lamps; (4) 4-foot miniature bipin (MiniBP) T5 standard output (SO); and (5) 4-foot MiniBP T5 HO lamps. Details on how these product classes were selected can be found in chapter 5 of this NOPR TSD. Table 10.1 shows all GSFL product classes and designates those that were considered to be representative.

Table 10.1 Product Classes for GSFLs

Lamp Type	For CCT ≤ 4,500 K Minimum Lamp Efficacy <i>lm/W*</i>	For CCT > 4,500 K Minimum Lamp Efficacy <i>lm/W</i>
4-foot medium bipin	Representative product class	Scaled from ≤ 4,500 K
2-foot U-shaped	Scaled from 4-foot medium bipin	Scaled from ≤ 4,500 K
8-foot single pin slimline	Representative product class	Scaled from ≤ 4,500 K
8-foot recessed double contact HO	Representative product class	Scaled from ≤ 4,500 K
4-foot T5 miniature bipin SO	Representative product class	Scaled from ≤ 4,500 K
4-foot T5 miniature bipin HO	Representative product class	Scaled from ≤ 4,500 K

* lm/W = lumens per watt

10.2.2 Trial Standard Levels

DOE analyzed the benefits and burdens of a number of TSLs for the GSFLs that are the subject of this rulemaking. Table 10.2 presents the TSLs and the corresponding representative

product class ELs. Each TSL is comprised of the same numbered efficacy levels for the corresponding non-representative product classes. For example, the 4-foot MBP with CCT > 4,500 K product class would have the same ELs as the 4-foot MBP with CCT ≤ 4,500 K product class for each TSL. See the engineering analysis in chapter 5 of this NOPR TSD for a more detailed discussion of the ELs.

Table 10.2 Trial Standard Levels for GSFLs by Efficacy Levels

Representative Product Class	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
4-foot MBP, CCT ≤ 4,500 K	EL 0	EL 0	EL 1	EL 2	EL 2
8-foot SP slimline, CCT ≤ 4,500 K	EL 0	EL 1	EL 0	EL 0	EL 2
8-foot RDC HO, CCT ≤ 4,500 K	EL 1	EL 2	EL 1	EL 1	EL 2
4-foot MiniBP T5 SO, CCT ≤ 4,500 K	EL 1	EL 1	EL 1	EL 1	EL 2
4-foot MiniBP T5 HO, CCT ≤ 4,500 K	EL 1	EL 1	EL 1	EL 1	EL 1

TSL 1 corresponds to setting energy conservation standards at the efficacy levels of the least efficient products currently on the market for each product class. The current standard for some product classes is well below the least efficient products on the market; TSL 1 would close this gap. For the 4-foot MBP and 8-foot SP slimline product classes, the baseline level of efficacy (EL 0) is required for TSL 1 because the least efficient products currently on the market just meet the existing standard at this baseline level. In the 4-foot MBP product class, basic 800 series full wattage lamps are at the baseline level. In the 8-foot SP slimline product class, less efficient 800 series full wattage lamps are at the baseline level. For the 8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO product classes, this TSL would set standards at EL 1. EL 1 represents the first level of efficacy at which there are commercially available products on the market for these product classes. In the 8-foot RDC HO product class, a full wattage lamp with 700 series rare earth phosphor would be required for TSL 1. For the T5 MiniBP SO and T5 MiniBP HO product classes, full wattage lamps with basic 800 series rare earth phosphor would be required for TSL 1. For the T5 MiniBP HO product class, 49 W and 47 W reduced wattage lamps are also at this level.

TSL 2 would set energy conservation standards for GSFLs that would bring all product classes to approximately the same level of rare earth phosphor. For the 4-foot MBP product class, the baseline level of efficacy (EL 0) is required for TSL 2. For the 8-foot SP slimline, T5 MiniBP SO, and T5 MiniBP HO product classes, TSL 2 would set energy conservation standards at EL 1. For the 8-foot RDC HO product class, TSL 2 would set energy conservation standards at EL 2. In all the above product classes, TSL 2 would require basic 800 series rare earth phosphor for full wattage lamps. For the T5 MiniBP HO product class, 49 W and 47 W reduced wattage lamps are also at this level.

TSL 3 represents the maximum NES and NPV that can be achieved without requiring EL 2 for any product class. TSL 3 would set energy conservation standards at EL 1 for the 4-foot MBP, 8-foot RDC HO, T5 MiniBP SO, and T5 MiniBP HO product classes. In the 4-foot MBP product class, TSL 3 would require an improved 800 series rare earth phosphor for full wattage

lamps. In the 8-foot RDC HO product class, TSL 3 would require 700 series rare earth phosphor for full wattage lamps. In the T5 product classes, TSL 3 would require basic 800 series rare earth phosphor for full wattage lamps. For the T5 HO product class, 49 W and 47 W reduced wattage lamps are also at this level. TSL 3 would set energy conservation standards at the baseline level (EL 0) for the 8-foot SP slimline product class in order to achieve maximum NES and NPV without going to EL 2. In the 8-foot SP slimline product class, less efficient full wattage 800 series lamps are at the baseline level.

TSL 4 represents the maximum NPV that was achievable in the analysis from any combination of ELs. TSL 4 would set energy conservation standards at EL 1 for the 8-foot RDC HO, T5 MiniBP SO, and T5 MiniBP HO product classes. In these product classes, TSL 4 would require basic 800 series rare earth phosphor for full wattage lamps. For the T5 HO product class, 49 W and 47 W reduced wattage lamps are also at this level. TSL 4 would set energy conservation standards at EL 2 for the 4-foot MBP product class. In the 4-foot MBP product class, TSL 4 would require use of premium 800 series (*i.e.*, high lumen) rare earth phosphor for full wattage lamps. For the 4-foot MBP product class, reduced wattage 28 W and 25 W lamps are also at this level. TSL 4 would set energy conservation standards at the baseline level (EL 0) for the 8-foot SP slimline product class in order to achieve maximum NES and NPV without going to EL 2. In the 8-foot SP slimline product class, less efficient full wattage 800 series lamps are at the baseline level.

TSL 5 represents the max tech EL for all GSFL product classes. TSL 5 also represents the maximum NES that was achievable in the analysis. TSL 5 would set energy conservation standards at EL 2 for the 4-foot MBP, 8-foot SP slimline, 8-foot RDC HO, and T5 MiniBP SO product classes. In the 4-foot MBP product class, TSL 5 would require premium 800 series (*i.e.*, high lumen) rare earth phosphor for full wattage lamps. For the 4-foot MBP product class, reduced wattage 28 W and 25 W lamps are also at this level. For the 8-foot SP slimline and T5 MiniBP SO product classes, TSL 5 would require improved 800 series rare earth phosphor for full wattage lamps. Reduced wattage 54 W and 50 W 8-foot SP slimline lamps are also at this level. For the T5 MiniBP SO product class, reduced wattage 26 W and 25 W lamps are also at this level. In the 8-foot RDC HO product class, TSL 5 would require basic 800 series rare earth phosphor for full wattage lamp. TSL 5 would set energy conservation standards at EL 1 for the T5 MiniBP HO product class. In this product class, TSL 5 would require basic 800 series rare earth phosphor for full wattage lamps. For the T5 HO product class, 49 W and 47 W reduced wattage lamps are also at this level.

10.3 INCANDESCENT REFLECTOR LAMPS

10.3.1 Representative Product Classes

In chapter 3 of this NOPR TSD, DOE identifies eight product classes for incandescent reflector lamps (IRLs). Rather than analyze all product classes, DOE selected certain product classes as “representative” to analyze in further detail. DOE selected standard spectrum IRLs

with a diameter greater than or equal to 2.5 inches and voltage less than 125 volts to be a representative product class for IRLs. Representative product classes are discussed in more detail in chapter 5 of this NOPR TSD. Table 10.3 lists the IRL product classes.

Table 10.3 Product Classes for IRLs

Lamp Type	Diameter	Voltage
Standard spectrum	> 2.5 inches	≥ 125
		< 125 (representative)
	≤ 2.5 inches	≥ 125
		< 125
Modified spectrum	> 2.5 inches	≥ 125
		< 125
	≤ 2.5 inches	≥ 125
		< 125

10.3.2 Trial Standard Levels

DOE analyzed the benefits and burdens of one TSL for the IRLs that are the subject of this rulemaking. Table 10.4 presents the TSL and the corresponding representative product class ELs. The TSL is comprised of the same numbered efficacy level for all eight IRL product classes. For example, TSL 1 contains EL 1 for all eight product classes. See the engineering analysis in chapter 5 of this NOPR TSD for a more detailed discussion of the ELs.

Table 10.4 Trial Standard Levels for IRLs by Efficacy Level

Representative Product Class	TSL 1
Standard Spectrum, Diameter > 2.5 inches, Voltage < 125 V	EL 1

TSL 1 represents the max tech EL for all product classes. TSL 1 can be achieved by either an halogen infrared (HIR) lamp with a lifetime of 2,500 hours or an improved HIR lamp that may utilize improvements in reflector coatings with a lifetime of 4,200 hours.

CHAPTER 11. SHIPMENTS ANALYSIS

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CHAPTER 11. SHIPMENT ANALYSIS

11.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy (DOE) used to project the future shipments of general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs) that would occur without updated energy conservation standards and under five trial standard levels (TSLs) for GSFLs and one TSL for IRLs.

DOE developed a consumer-choice-based model to estimate shipments of GSFLs and IRLs. The model projects consumer purchases (hence shipments) based on sector-specific consumer sensitivities to first costs and operating costs of lamps, as revealed by historical data. To account for non-economic consumer behaviors a technology diffusion model and a technology acceptance factor are superimposed on the shipments model. The model allows switching between certain product classes, where there is historical evidence that switching has occurred.

Because of the complexity of the consumer-choice-based shipments analysis, the shipments model was executed as a separate computer model written in the Python language. The inputs and outputs of the shipments model were embedded in the national impact assessment (NIA) model, which implemented in a Microsoft Excel[®] spreadsheet, available on regulations.gov, docket number EERE-2011-BT-STD-0006 at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006.

Shipments projections are a necessary input to calculations of the national energy savings (NES) and net present value (NPV) in the national impacts analysis (NIA), as well as to the manufacturer impact analysis (MIA). For each lamp type considered DOE projected the change in shipments that would occur under different efficiency levels. Because the model accounts for product switching across compatible products, exploring the impact of a standard on any given product requires that the standard levels for all substitutable products be set as well. Accordingly, developing a trial standard level (TSL) involves setting the minimum assumed efficiency level (EL) for all analyzed lamp types (as defined in section 11.1.1), using the efficiency levels (ELs) developed in chapter 5 of this TSD. In this NOPR analysis DOE defined 5 TSLs, listed below in Table 11.1.1 for GSFLs and Table 11.1.2 for IRLs, and described in chapter 10 of this TSD, to explore the potential range of energy savings, costs, and benefits obtainable from the standards.

Table 11.1.1 GSFL Efficiency Levels for each Trial Standard Level for Each of the Modeled Lamp Types

Modeled Lamp Type	Base case (No new standards)	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	Baseline	Least Efficacious lamp on market	Same REO levels in all PCs	Max NES with no EL 2	Max NPV	Max Tech / Max NES
4-foot MBP*	Baseline	Baseline	Baseline	EL 1	EL 2	EL 2
8-foot SP** slimline	Baseline	Baseline	EL 1	Baseline	Baseline	EL 2
8-foot RDC† HO ††	Baseline	EL 1	EL 2	EL 1	EL 1	EL 2
4-foot T5, MiniBP SO ‡	Baseline	EL 1	EL 1	EL 1	EL 1	EL 2
4-foot T5, MiniBP HO	Baseline	EL 1	EL 1	EL 1	EL 1	EL 1

* MBP = medium bi-pin, ** SP = single pin, † RDC = recessed double contact, †† HO = high output, and ‡SO = standard output.

Table 11.1.2 IRL Efficiency Level for Trial Standard Level

Modeled Lamp Type	Base case (No new standards)	TSL 1
All IRL	Baseline	EL 1

To evaluate the impact of the TSLs on shipments of the two categories of lamps—GSFLs and IRLs—DOE calculated the difference between the shipments in each TSL and those of the corresponding base case for each lamp type. All assumptions for a given TSL are identical to those of its corresponding base case, except that lamp options that do not meet the standard are excluded in the standards case. The cumulative impact of each TSL on shipments is determined by summing the annual impacts over the 2017 through 2046 analysis period. For each TSL, DOE calculated its best estimate of the impact of each TSL on shipments, broken down by lamp type.

In addition to the best estimate, which is referred to as the Reference scenario in this document and uses the reference values for all inputs in the NIA spreadsheet, DOE ran alternative scenarios for two purposes:

- Sensitivity Analyses explore uncertainties inherent to some model parameters. For GSFL, DOE considered one scenario that examined the effect of high rare earth oxide (REO) prices, and it considered another scenario that did not allow market share to be allotted to the modeled baseline lamps for 8-foot T8 HO, T5 SO and T5 HO. For IRL, DOE

considered a scenario in which manufacturers meet the proposed standard with higher-wattage, shorter lived lamps and a scenario with high Xenon prices.

- Impact Analyses assess the impact of certain model parameters on shipments. DOE does not believe these scenarios represent likely market outcomes and are included for informational purposes only. For GSFL and IRL, DOE assessed the impact of the growth of lighting controls, and solid-state lighting (lighting that uses light emitting diodes (LEDs)) on shipments, by running scenarios without the expected growth included in the Reference scenario. DOE also considered the impact of assuming that passing a standard will not induce any additional switching between product classes, beyond what occurs in the base case. The impacts of a 9-year analysis period were also analyzed.

This chapter reports the effects on shipments of all the TSLs and alternative scenarios (Chapter 12 of the TSD, which describes the NIA, documents the resulting effects on NES and NPV). Section 11.2 presents the model methodology. Section 11.3 describes model calibration and inputs. Section 11.4 describes the alternative analyses. Section 11.5 presents the shipments projections for the GSFL and IRL base cases, standard cases, and alternative analyses.

11.1.1 Analyzed Product Classes, Market Sectors, and Market Segments

As elsewhere in this TSD, DOE aggregated product classes into a smaller set of *lamp types*, each representing one or more product classes, constrained by the representative products identified in the engineering analysis (chapter 5 of this TSD) and by the lack of sufficient disaggregation of shipments data needed to determine market shares by individual product class. For the purposes of projecting future shipments, DOE modeled the lamp types and sectors shown in Table 11.1.3. The properties of the representative products were assumed to reflect similar products within the lamp type as a whole. Specifically, DOE used GSFL lamps with a correlated color temperature (CCT) less than 4,500K to be representative of those greater than or equal to 4,500K, and it used standard spectrum IRLs with diameters greater than 2.5 inches operating on less than 125 volts as representative of all covered IRLs.

Table 11.1.3 Lamp Types Used in the Shipments Model

Lamp Type	Sector	
	Residential	Commercial and Industrial
GSFLs		
4-foot MBP	X	X
8-foot SP slimline		X
8-foot RDC HO		X
4-foot T5, MiniBP SO		X
4-foot T5, MiniBP HO		X
IRLs	Residential	Commercial
All IRLs	X	X

DOE did not directly model shipments of 2-foot U-shaped lamps because of their relatively small market share. Following the procedure adopted in the 2009 GSFL-IRL rulemaking¹, DOE scaled the results from the 4-foot MBP lamp type to approximate the NES and NPV of the 2-foot U-shaped lamp type. Specifically, it assumed that U-shaped lamps maintain a market share equivalent to 1/25th of the base-case 4-foot MBP market, based on the

ratio of the sum of shipments of 4-foot MBP T8s from 2006 – 2011 and the sum of 2-foot T8 U-shaped lamps during the same period reported by the National Electrical Manufacturers Association (NEMA) (see chapter 3 of this TSD). Shipments of U-shaped lamps were held fixed at their base-case values for all standards cases, since DOE believes that no other product classes contain common substitutes for U-shaped lamps.

For all lamp types DOE aggregated across the commercial and industrial sectors, because of both the similar applications for these lamp types and the relatively small contribution of the industrial sector. Residential usage of GSFLs was considered negligible for all lamp types except for 4-foot MBP lamps.

In addition to modeling the representative products described previously, DOE incorporated T12 lamps into its shipments analysis. While new production of T12 lamps appears unlikely under the 2012 lamp efficiency standards, because of their relatively long lifetimes and their large historical market share, they still constitute a significant fraction of the existing lighting stock. Therefore, the shipments model addresses replacements for existing stock of T12 lamps and ballasts with new T5 and T8 lamps and ballasts. Specifically, the model includes three additional T12 ballasts and lamp options: 4-foot MBP T12, 8-foot SP slimline T12, and 8-foot RDC HO T12. DOE assumed that no new T12 lamp-and-ballast systems would be shipped during the analysis period, but DOE did model new shipments of T12 lamps for the relamping of existing systems, as T12 lamps are available that are exempt from current standards.

In its projections of IRL shipments, DOE aggregated across all IRL product classes (standard- versus modified-spectrum, less than and greater than or equal to 125 V, and less than or equal to and greater than 2.5 inches in diameter). The shipments model includes shipments for all covered IRLs that are commercially available. As with the modeling of 4-foot MBP GSFL shipments, DOE aggregated commercial and industrial sector IRLs and analyzed residential lamps separately.

11.2 SHIPMENTS MODEL METHODOLOGY

This section describes the conceptual framework of the model and the modeling assumptions. Model calibration and inputs are addressed in section 11.3.

11.2.1 Conceptual Framework of the Shipments Model

The shipments model estimates the changing market distributions of the covered lamps broken down by lamp type and efficiency level for input to the NIA analysis. In its shipments and NIA modeling, DOE represented each lamp type analyzed by a set of several *lamp options* covering various ELs and wattages, with properties drawn from the representative products identified in the engineering analysis (chapter 5 of this TSD). Table 11.2.1 and Table 11.2.2 summarize the wattages and efficacies of representative IRL and GSFL options that meet the indicated efficiency levels in all lamp types. Table 11.2.2 also includes lamp option identifiers (IDs) that are used in section 11.3 to further describe model assumptions about the properties of GSFL lamps and of lamp-and-ballast systems. As shown, in some cases, there are multiple representative lamps options for a given EL. (For a complete listing of IRL properties, see Table

11.3.18) A more complete description of the characteristics of these representative products is presented in section 11.3.6.

Table 11.2.1 IRL Options Used in Shipments Model

Lamp Option	Nominal Wattage	Efficacy (lm/W)
Baseline 1	60	17.8
EL1 Lamp 1	56	18.5
EL1 Lamp 2	55	18.5

Table 11.2.2 GSFL Lamp Types and Lamp Options Used in Shipments Model

Lamp Type	EL	Lamp Option ID	Lamp Diameter	Nominal Wattage	Efficacy (lm/W)
4-foot MBP	Baseline	L1.0.1	T8	32	89.2
	EL1	L1.1.1	T8	32	90.0
	EL2	L1.2.1	T8	32	95.4
		L1.2.2	T8	28	96.0
		L1.2.3	T8	25	93.0
8-foot SP slimline	Baseline	L2.0.1	T8	59	96.5
	EL1	L2.1.1	T8	59	98.2
		L2.2.1	T8	59	99.0
		L2.2.2	T8	54	105.6
		L2.2.3	T8	50	108.0
8-foot HO	Baseline	L3.0.1	T8	86	92.0
	EL1	L3.1.1	T8	86	95.2
	EL2	L3.2.1	T8	86	97.6
T5 SO	Baseline	L4.0.1	T5	28	94.6
	EL1	L4.1.1	T5	28	104.3
	EL2	L4.2.1	T5	28	109.7
		L4.2.2	T5	26	111.5
		L4.2.3	T5	25	116.0
T5 HO	Baseline	L5.0.1	T5	54	83.6
	EL1	L5.1.1	T5	54	92.9
		L5.1.2	T5	49	102.0
		L5.1.3	T5	47	102.1

Lamp-and-ballast interactions were explicitly addressed in the shipments model for two reasons. First, the existing ballast limits the lamp options available to consumers. Second, the ballast to which a lamp is paired affects its energy use, which in turn affects lamp and ballast shipments in the consumer choice module through its effect on operating costs. Therefore, the shipments model first computes ballast shipments before it calculates GSFL shipments. None of the different lamp types considered in this analysis can be interchanged with another lamp type on the same ballast, so the lamp types are associated with non-overlapping sets of ballast options with properties listed in Table 11.3.9 and Table 11.3.10.

The ballast options utilize different technologies for lamp starting and operation, as well as having different ballast factors within those technologies in some cases (for details, see chapter 5 of this TSD). In this document, the term *ballast technology* will be used to refer to sets of ballasts with the same starting and operation technology (instant-start, programmed-start, or dimming ballasts). The term *ballast option* then refers to the individual representative ballasts, possibly having different ballast factors, within each ballast technology. The national energy consumption of GSFLs is therefore affected not only by the distribution of lamps among the various ELs, but also by the distribution of ballasts among the various ballast options.

The shipments model has three main interacting elements: (1) a lumen demand module, which estimates the demand for GSFL and IRL lighting for each year of the analysis period; (2) a consumer choice module, which assigns shipments to lamp types and efficiency levels based on consumer sensitivities to first costs and operation and maintenance costs; and (3) a price learning module, which projects future lamp and ballast prices based on historic price trends. To account for product switching, the consumer choice model consults substitution matrices, which specify the allowable product choices that consumers have available (lamp types, ballast options, or lamp-and-ballast combinations), depending on whether they are renovating lighting systems, installing lighting systems in new construction, or replacing lamps. Based on the estimated prices, the consumer choice model allocates the national lumen demand to the lamp types and lamp options for each year of the analysis period, subject to the constraints of the standards case under consideration.

11.2.1.1 Lumen Demand Module

A central assumption of the model is that the amount of light desired to fully light a space (lumen capacity demand per square foot, measured in units of lumens per square foot) is assumed to remain unchanged over the analysis period. That is, sector-specific lumen demand stays constant in terms of the total desired lumen capacity per square foot, where lumen capacity is the total maximum (non-dimmed) light output. However, total national lumen demand grows proportionally with floor area (residential, commercial, and industrial). Therefore, the total lumen demand was adjusted based on the sector-specific floor-space growth rates extracted from *Annual Energy Outlook 2013 (AEO 2013)*.²

While lumen capacity demand per square foot is expected to remain constant, DOE expects the demand for GSFL and IRL products to be eroded by increased penetration of solid-state lighting (*i.e.*, lighting that uses LEDs for illumination) into the market. For its best-estimate (reference) scenario, DOE assumed that LED penetration would match the LED incursions forecast for DOE's Solid-State Lighting Program³, as described in section 11.4.2.

At the same time that LED lighting is eroding GSFL and IRL lumen capacity demand per square foot, the increasing penetration of lighting controls is expected to erode the lumen-hour demand per year per square foot, by turning lights off or down when they are not needed or wanted. While that erosion in conventional lighting demand will mainly affect energy use and, therefore, the NIA, controls penetration can have an indirect effect on lamp shipments via its impact on lamp lifetime. DOE's projection of lighting controls penetration over the analysis

period is described in appendix 11A. The impacts on lamp lifetimes are described in section 11.2.2.2.

11.2.1.2 Consumer Choice Module

The consumer choice module constitutes the analytical heart of the shipments model. In each year of the analysis period the consumer choice model assigns the market share of new purchases (shipments) to each lamp type, and to each EL within each lamp type, subject to the lamp options (or lamp-and-ballast options, as appropriate) that are available to the consumer. The simplifying assumption of the model is that lamp efficacies exist only at the discrete levels defined by the ELs in the engineering analysis. First cost and operations and maintenance (O&M) costs are the key variables that the model uses to ‘decide’ which option is selected, where consumer sensitivity to first costs and O&M costs are inferred from historical data.

For fluorescent lamps the shipments model accounts for the costs and energy savings of both the lamps and their associated ballasts. Ballast shipments are tracked separately from lamps shipments, because ballasts last longer than lamps, and they affect the choice of replacement lamps, but are generally purchased together with a lamp. (The model assumes that, when a ballast is replaced, the lamp (or lamps) is replaced with it.) For both the ballasts and the lamps, the consumer choice model is used to make the selection. When a ballast is replaced, the consumer choice module is first run to select a lamp type. The cost calculation assumes that the first cost for the ballast includes the cost of the lamps that will be installed on it, and accounts for the ballast O&M costs (which include the labor cost of lamp replacement, given the average lamp lifetime for that ballast technology).. Once the lamp type is selected the consumer choice module is run to select a ballast option to drive the selected lamp type. Finally the consumer choice is run to select the particular lamp option (efficiency level) to couple to the selected ballast. Every choice is subject to a constraint matrix that limits the available options depending on whether the selection is being made for new construction, retrofit and renovation, or lamp replacement. Generally selections are made to maintain lumen capacity to within 10% of desired levels, with some consumers willing to accept reduced lumen capacity for energy savings. Details of the choice modeling are described in section 11.2.2, and details of the input parameters and assumptions are given in section 11.3.

DOE adopted an existing consumer choice model for this NOPR analysis that also had been used by DOE to project the penetration of LEDs into the U.S. lighting market.³ The model, also used by others,^{4,5} allocates market shares as an aggregate of many individual purchasing decisions. As shown in Figure 11.2.1 the consumer choice module couples an econometric conditional logit model with a technology diffusion model, using a Bass diffusion curve,⁶ which limits the technology adoption rate based on historical observations. The Bass diffusion curve captures barriers to market entry,⁶ like lack of consumer information, that diminish over time with consumer exposure to the growing market. As those barriers diminish, the product achieves a market share that is more nearly described by the economic factors captured by the logit model.

While the technology diffusion model captures how product adoption increases over time, there are also non-economic reasons for consumer preferences that persist over time and are not captured in this model. This analysis uses acceptance factors, which place a cap on the

potential market share of certain options, to capture these deviations from economic factors. For example, economic factors do not fully explain consumers' persistent preference for 4-foot T8 lamps over 8-foot T8 lamps, which might be explained by aesthetics and greater ease in handling. In this NOPR analysis, the logit calibration was based on aggregate historical shipments data, provided by NEMA, for T12, T8 and T5 lamps, combined with cost estimates from the 2011 lamps rulemaking¹. The acceptance factors were then used to calibrate the consumer choice module to how the actual market shares of certain lamp types and lamp options considered in the shipments model differed from the logit-based predictions. For example, an acceptance factor for 8-foot slimline lamps was used to reflect the much larger market share of 4-foot, rather than 8-foot, T8 lamps. The logit and diffusion model elements are described in more detail in the remainder of this section; the calibration of the consumer choice model is detailed in section 11.3.4.

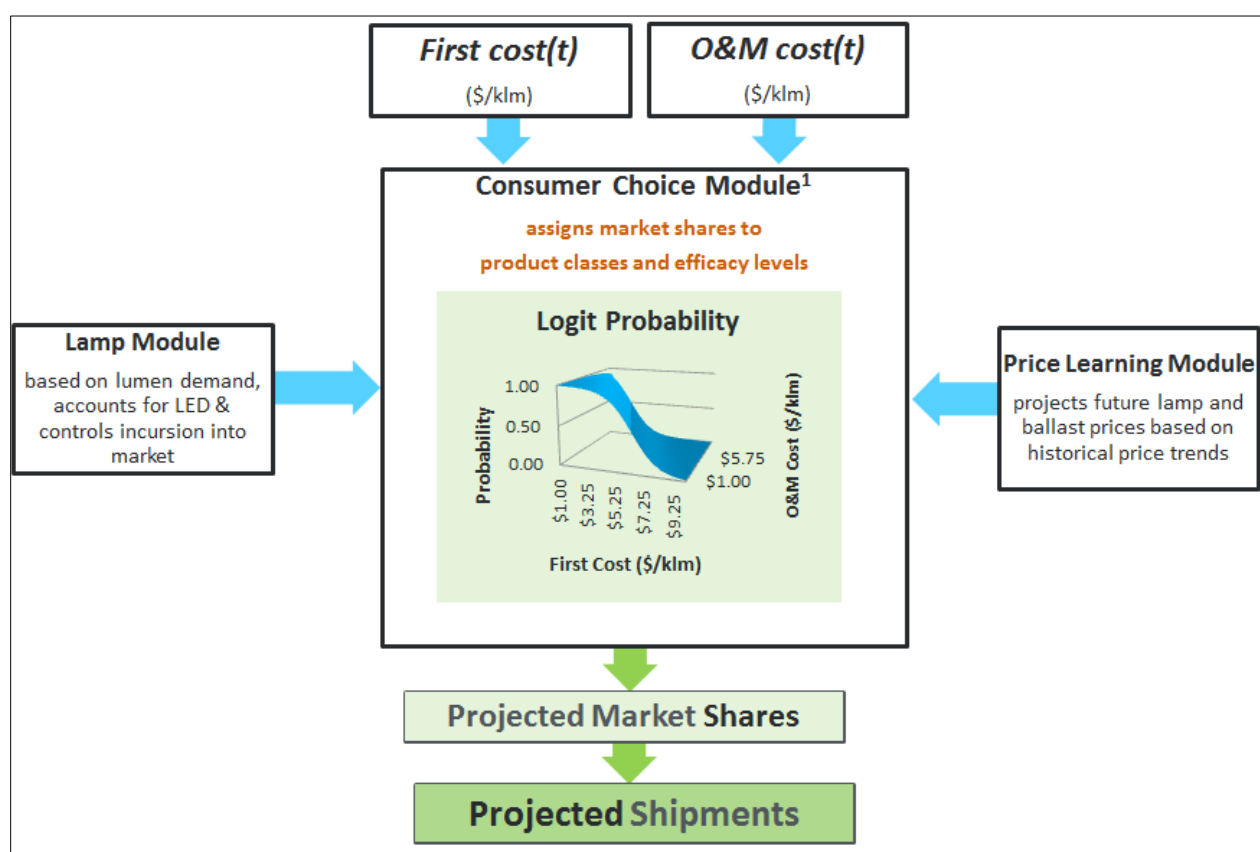


Figure 11.2.1 Schematic Representation of the Consumer Choice Model

The Conditional Logit Model. The conditional logit model calculates the probability that a consumer will purchase product j , (P_j)—based on a logistic curve probability function of the form:

$$P_j(z) = \frac{e^{z_j}}{\sum_{i=1}^n e^{z_i}}$$

Eq. 11.1

Where:

$P_j(z)$ = the probability a consumer will purchase product j among n possible options, and
 z = the ‘logit’, which is defined as follows:

$$z_j = \beta_{FC} * FC_j + \beta_{OM} * OM_j$$

Eq. 11.2

Where:

β_{FC} = consumer sensitivity to first cost,

FC_j = first cost of product option j (\$/klm),

β_{OM} = consumer sensitivity to operations and maintenance cost, and

OM_j = operations and maintenance cost of product option j (\$/klm).

The regression coefficients (beta values), which represent the consumers’ sensitivity to first cost (β_{FC}) and O&M cost (β_{OM}), are determined from a logistic regression that fits historical shipments, first costs (FC), and O&M costs (OM), normalized on a per kilolumen basis, to the logistic curve. The kilolumen output used to normalize the costs is the same reference value for all lamp and lamp-ballast options associated with each lamp type, as discussed in Section 11.2.2. Sections 11.2.2.3 and 11.2.2.4 describe how first costs and O&M costs are handled for the two categories of lamps and for ballasts.

The Bass Technology Diffusion Curve. The Bass diffusion curve sets the maximum market share the model will allocate to an individual lamp type or ballast option at any given point of time following its introduction to the market, given the technology diffusion rate for lighting products. If the consumer choice module initially allocates a market share that is too large according to the diffusion curve, the excess share is sent back to the consumer choice module to be reallocated with that particular product option eliminated from the choice matrix.

A Bass adoption curve is a 2-parameter diffusion curve widely used to describe how new products enter into markets. The two parameters, CE and CI , represent external and internal influences, respectively, on markets; see Bass⁶ and Pacific Northwest National Laboratory (PNNL)¹⁷ for more details. If the fraction of the market is zero at time = 0, the Bass diffusion curve is expressed in the following way:

$$MS(t) = \frac{1 - e^{-(CE+CI)t}}{1 + \left(\frac{CI}{CE}\right) e^{-(CE+CI)t}}$$

Eq. 11.3

Where:

$MS(t)$ = market share at time t ,

t = time since the product was introduced to the market (yr),

CE = the coefficient of external influence, and

CI = the coefficient of internal influence.

11.2.1.3 Price Learning Module

As described previously, the consumer choice model uses product prices as inputs. Consistent with current practice, DOE has adopted a ‘price learning’ model to project product prices over the analysis period.^{7,8} As originally defined, price learning reflects systematic decreases in manufacturing costs resulting from cumulative production experience. When price learning analyses are considered on an industry-wide basis, rather than at the manufacturer level, and when they include learning effects downstream of production (for example, increased efficiencies in product distribution), the price learning curve is typically referred to as an experience curve, but it takes the same mathematical form. Consequently a broad range of cost and price metrics have been used to quantify learning rates for appliances and equipment (see, for example, Weiss et al., 2010, Table A1).⁹

Historical data are used to estimate the learning impact by fitting the data to a learning curve of the following form:

$$p(X) = p_{init} * X^{-b} \quad \text{Eq. 11.4}$$

Where:

$p(X)$ = the price of a particular product as a function of cumulative production (2011 dollars),
 p_{init} = the initial price of the product at the time of market introduction (2011 dollars),
 X = cumulative production (total shipments) of the product from the time of its market introduction (number of units), and
 b = a positive constant known as the learning rate parameter.

As described in section 11.3.5, DOE used historical price and shipments data from the U.S. Census to determine the cumulative historical production and prices of lamps and ballasts sold into the U.S. market and, thus, to calibrate the learning rate parameter, b .

Eq. 11.4 can be used to obtain a projection for the price of lamps or fluorescent ballasts in each year, $p(y)$, if the cumulative production is written explicitly as a function of time:

$$X(y) = \sum_{v=y_{init}}^{y-1} s(v) \quad \text{Eq. 11.5}$$

Where:

$X(y)$ = the cumulative production (total shipments) of a product between the year of its introduction and year y (number of units),
 y = the current year,
 v = the vintage, or year, in which a product was shipped to market,

y_{init} = the year of the product's market introduction, and
 $s(v)$ = the shipments in vintage year v (number of units; see Eq. 11.36, Eq. 11.40, and Eq. 11.48)

Eq. 11.4 and Eq. 11.5 can then be combined to compute a price learning factor:

$$PLF(y) = \left(\frac{X(y)}{X(2011)} \right)^{-b} \quad \text{Eq. 11.6}$$

Where:

$PLF(y)$ = the price learning factor in year y , and
all other variables are defined in Eq. 11.4 and Eq. 11.5.

The price learning factor is then used to calculate the price of any lamp option in any year, given its 2011 price, as determined in the engineering analysis (see chapter 5 of this TSD), using the following equation^a:

$$p(y) = PLF(y) \times p(2011) \quad \text{Eq. 11.7}$$

Where:

$p(y)$ = the price of a particular lamp option in year y ,
 $p(2011)$ = the price of a particular lamp option in 2011, and
 $PLF(y)$ is as defined in Eq. 11.6.

11.2.1.4 The Coupled Model

The shipments model uses the price learning rate and cumulative production information described in the previous section to calculate the price of each product in any year of the analysis, given the additions to the cumulative production estimate by the shipments model up to that point. Accordingly, the model proceeds step-wise each year to calculate product shipments based on prices and O&M costs via the demand and consumer choice modules. It then calculates the following year's product prices based on that year's shipments.

11.2.2 Lamp Specific Modeling and Assumptions

DOE projected the annual shipments of GSFLs and IRLs by computing the lumen demand for new construction and lighting renovation, as well as the lumen demand for replacement of failed lamps in each year, to obtain the total demand for new lighting shipments:

^a In the case of GSFLs, this equation is applied only to the portion of the lamp price that does not include the price of rare earth elements, as discussed in appendix 11B.

$$D(y) = D_{NCR}(y) + D_F(y)$$

Eq. 11.8

Where:

y = the year of the analysis period^b,

$D(y)$ = the total lumen capacity demand for new shipments in year y (lm),

$D_{NCR}(y)$ = the total lumen capacity demand for new construction and lighting renovations (lm), and

$D_F(y)$ = the national lumen capacity demand for replacement of failed lamps and lamp-and-ballast systems (lm).

DOE then apportioned this demand among the various technology options via the consumer choice module to determine the shipments of each lamp and ballast option in each year. The lamp options DOE considered in the shipments analysis are discussed in Section 11.3.6.

Because the different lamp and lamp-ballast options associated with each lamp type have slightly different lumen outputs, DOE assumes that lamp shipments meet the underlying lumen capacity demand approximately, but not necessarily exactly. DOE converts lumen capacity demand to lamp demand by selecting a reference lumen package for each lamp type, Λ_{LT} , which is representative of typical lumen output for that lamp type. The calculation of these reference values is discussed in Section 11.3.6.4.

Given values for the retirements and new shipments in year y , as well as the total stock in year $y-I$, the stock of lamps (for IRLs) or lamp-and-ballast systems (for GSFLs) in year y can be calculated as:

$$S(y) = S(y-1) - R(y) - F(y) + s(y)$$

Eq. 11.9

Where:

$S(y)$ = the national stock of lamps or lamp-and-ballast systems in year y (number of units),

$R(y)$ = lamps or lamp-and-ballast systems retired for lighting renovations in year y (number of units),

$F(y)$ = lamps or lamp-and-ballast systems that fail (or are removed for scheduled relamping) and are replaced in year y (number of units), and

$s(y)$ = the total shipments of new lamps or lamp-and-ballast systems in year y (number of units).

^b The time variable y in this analysis is a discrete variable representing the year of the analysis period. Throughout the remainder of this analysis, quantities that depend on y will be written in the form $D(y)$, which is more typically used for functions of a continuous variable, rather than the usual subscript form that is conventionally used for discrete variables D_y . This is done for the sake of avoiding confusion with other subscripts used in the notation.

Eq. 11.9 requires the stock to be initialized at the beginning of the analysis period. The technique for initializing the stock model is described in section 11.1.1. For the purposes of computing the NES in the NIA (chapter 12 of this TSD), however, it is not necessary to compute the total installed stock of lamps and lamp-and-ballast systems in the United States. The only portion of the stock that is relevant to this calculation is made up of lamps shipped during or after the compliance year of the standard being considered, y_{rule} . For this analysis, DOE refers to that relevant portion of the stock as the *operating stock shipped during the analysis period* (OSSDAP). The OSSDAP in each year, denoted $S'(y)$, can be computed from Eq. 11.9 with the assumption that $S'(y_{rule} - 1) = 0$.

A complication to this basic picture arises in the case of projecting GSFL shipments. The choice of a fluorescent lamp by a consumer depends on the ballast to which the lamp will be coupled. If a consumer is replacing a lamp on an existing ballast, the lamp must be compatible with the ballast. Therefore, the GSFL part of the shipments model must account for the shipments and stock, throughout the analysis period, of ballasts that can be coupled to the analyzed lamp types.

DOE therefore models GSFL shipments in two steps: first, a turnover model for ballasts is computed to project ballast shipments and stock using the equations described previously; then, the lamp shipments and stock are derived from the ballast projection by computing the lamp-replacement probability on the projected stock of ballasts. As mentioned in Section 11.2.1, DOE considered a variety of different ballast options associated with each lamp type, including instant-start, programmed-start, and dimming ballast technologies; as well as ballast options with high and low ballast factors within some of the ballast technologies. DOE then considered coupling different lamp options to each of the ballast options, subject to the requirements that the lamps and ballasts are compatible and that the resulting lamp-ballast systems provide sufficient light output. The details of the ballast options considered, and the details of the lamp options for each ballast option, are discussed in Section 11.3.6.

With that caveat, the two equations presented above are the fundamental equations underlying the shipments and stock modeling of both lamp categories in this analysis. The remainder of this section will be devoted to computing the various components of these equations for IRLs, GSFLs, and for fluorescent ballasts as a preliminary step to computing the GSFL shipments and stock, starting with lumen demand.

11.2.2.1 Modeling Lumen Demand for New Construction and Renovations

To project the lumen demand for new construction, DOE assumed that the demand for lumen capacity per square foot of new floor space (lm/ft^2 at maximum lamp output) is constant during the analysis period, so that overall lumen demand grows at the same sector-specific annual growth rate as floor space. Thus, the annual lumen demand for new construction (D_{NC}) for a particular lamp type and sector is given by:

$$D_{NC,i}(y) = K_i(y_0)[(1 + \gamma)^{y-y_0} - (1 + \gamma)^{y-y_0-1}]$$

Eq. 11.10

Where:

$D_{NC,i}(y)$ = the total lumen capacity demand for new construction using lamp type i (lm),
 $K_i(y_0)$ = the total lumen capacity (lm at maximum output) of the installed stock of lamp type i in year y_0 in the sector being analyzed (lm),
 y_0 = the initial year of the model, and
 γ = the sector-specific, 30-year (2010-2040) average floor space growth rate projected by *AEO2013*.

In addition, DOE assumes that a fixed percentage of the lamp stock in each year is removed from service for renovations or lighting retrofits. The number of units (IRLs or fluorescent lamp-and-ballast systems) from each lamp type removed for renovations in year y is then:

$$R_i(y) = S_i(y - 1)f_{ren} \quad \text{Eq. 11.11}$$

Where:

$R_i(y)$ = stock of lamp type i removed for renovation in year y (number of units),
 $S_i(y - 1)$ = total installed stock (number of units) of lamp type i in year $y-1$ (computed in the following sections for IRLs and for fluorescent ballasts), and
 f_{ren} = fraction of the stock retired for renovations in each year.

This is added to the new-construction demand to yield the total lumen demand for new construction, renovation, and retrofits:

$$D_{NCR,i}(y) = D_{NC,i}(y) + R_i(y)\Lambda_i \quad \text{Eq. 11.12}$$

Where:

$D_{NCR,i}(y)$ = total lumen capacity demand for new construction or renovation using lamp type i in year y (lm), and
 Λ_i = lumen package of the reference lamp or lamp-and-ballast system for lamp type i , as discussed in the previous section (lm/unit).

The total demand for new construction, renovation, and retrofits is then given by the summation over all lamp types within each product (GSFL or IRL) and sector, as appropriate.

DOE took the fraction f_{ren} to be 4.7% of the total commercial and industrial stock based on a study of nonresidential renovation and remodeling in California.¹⁰ For the residential sector, DOE took f_{ren} to be 1% of the total stock, following the assumptions used in the 2011 fluorescent ballast rulemaking.¹¹ Shipments projections for GSFLs and IRLs are computed independently for the sectoral breakdowns indicated in Table 11.1.3.

11.2.2.2 Modeling the Retirement of Lamps and Lamp-and-ballast Systems

DOE determined the lumen demand for replacement shipments in a given year by computing the number of shipments from previous years that would be expected to retire in that year. DOE based its model for the retirement of lamps and ballasts on the Weibull distribution. The probability that a particular unit survives to a time t after its initial installation is:

$$w_S(t) = \begin{cases} \exp\left(-\left(\frac{t-d}{\lambda T}\right)^k\right), & t > d \\ 1, & t \leq d \end{cases} \quad \text{Eq. 11.13}$$

Where:

$w_S(t)$ = the probability that a unit survives to time t after its initial installation,
 t = the time since installation, in units of either hours or years, which is always nonnegative,
 T = a characteristic lifetime for the lamp or ballast, in the same units as t ,
 d = a delay parameter specifying the minimum lifetime of the unit, in the same units as t ,
 k = a parameter controlling the shape of the distribution, and
 λ = a parameter controlling the characteristic retirement age.

The specific parameters and time units that DOE used to specify the survival probability of different lamps and ballasts are summarized in Table 11.2.3. Their derivations are described later in this section.

Table 11.2.3 The Parameters and Time Units of the Weibull Distributions Used in the Shipments Analysis

Product	Time Units	Delay parameter d	Weibull shape parameter k	Weibull scale parameter λ	Characteristic Lifetime T
IRL	Hours	0	4.26	1.02	Lamp life hours (Table 11.3.18)
GSFL	Hours	0	5.50	1.10	Lamp life hours (Table 11.3.11)
Fluorescent ballast – Residential Sector	Years	2.00	2.50	1.02	15.0
Fluorescent ballast – Commercial Sector	Years	1.50	5.00	1.04	12.6
Fluorescent ballast – Industrial Sector	Years	0	5.00	0.92	10.3

It is more computationally useful in many cases to consider the probability that a lamp retires during some well-defined time interval—during the tenth year of its life, say, or the

5,000th hour of its operation. In this discussion, the probability that a unit retires between time $t-1$ and time t is written as:

$$w_R(t) = w_S(t - 1) - w_S(t) \quad \text{Eq. 11.14}$$

Where:

$w_R(t)$ = the probability that a unit retires between time $t-1$ and time t ,
 $w_S(t)$ = the survival probability defined in Eq. 11.13, and
 t = the time since installation as defined following Eq. 11.13.

IRL Retirement. As described previously, the Weibull retirement distribution for IRLs depends on the characteristic lifetime, T , of the IRL. To determine T for the purposes of the shipments modeling, the rated lifetime for each lamp option given in the engineering analysis (chapter 5 of this TSD) is adjusted to account for the impact of dimmers, where applicable, on lamp life. Operating an incandescent lamp dimmed (*i.e.*, at reduced wattage) increases lamp lifetime, often by a significant factor.

To account for this, DOE made use of the dimmer-related correction factors discussed in appendix 6A of this TSD. DOE assumes that operating an IRL on a dimmer will lead to a 20% reduction in energy consumption on average; this corresponds to a factor of 3.94 increase in lamp lifetime for individual incandescent lamps. DOE assumed that 29% of residential IRLs and 5% of commercial IRLs operate on dimmers and that these fractions are constant with time.^c These fractions imply that the national average lamp lifetimes in each sector increase by 85% and 15%, respectively, with respect to non-dimmed lamps. Therefore, in the shipments analysis, DOE adjusts upward by these amounts the estimated lifetime from the engineering analysis for IRLs.

DOE used the Weibull retirement distribution to compute an IRL survival function that is defined as a function of the total hours of lamp use (see Table 11.2.3). Thus, computing the lamp failures in each year required transforming the survival function from a function of the hour h to a function of the year a of a particular lamp's lifetime. DOE did this by convolving the Weibull retirement distribution, Eq. 11.14, with the same sector-specific hours-of-use distribution, $f(u)$, that was used in calculating the life-cycle cost (LCC) (chapter 8 of this TSD)^d:

^c Since incandescent dimmers are a common, mature, widely available technology that provides utility in only certain applications, DOE assumes that the penetration of dimmers has already reached its equilibrium level. Growth in controls penetration for IRLs in the model is assumed to be purely in switch-based controls, not in dimmers, and such growth is assumed to occur only in the commercial sector.

^d In principle this distribution should be adjusted to account for the increasing penetration over the analysis period of switch-based controls, like timers and occupancy sensors, in the commercial sector. However, the impact of this effect is relatively small (typically around 15% on average across all shipments if controls reduce usage by 30%) and will have a negligible impact given the very short lifetimes of commercial IRLs, so DOE neglects this effect in its shipments analysis. However, the impact on energy consumption of switch-based controls is accounted for in the NIA.

$$P_R(a) = \sum_{h=0}^{h_{max}} w_R(h) f(h/a)$$

Eq. 11.15

Where:

$P_R(a)$ = probability of lamp retirement in year a of lamp's life,
 $w_R(h)$ = the Weibull retirement function, as defined in Eq. 11.14,
 a = the lamp's age (yr),
 h = the total time that the lamp has been operated (hr),
 h_{max} = the maximum expected lifetime of a lamp (hr), and
 $f(h/a)$ = hours of use distribution $f(u)$ evaluated at the value $u=h/a$.

To parameterize the Weibull distribution in Eq. 11.15, DOE uses the parameters determined from laboratory testing of incandescent lamp failure rates.¹² These parameters are listed in Table 11.2.3.

From the probability function, Eq. 11.15, one can calculate the average lamp lifetime measured in years, L , with all parameters defined as in Eq. 11.15:

$$L = \sum_{a=0}^{\infty} a P_R(a)$$

Eq. 11.16

That probability function is also used to compute the expected lamp failures in year y , given a time series of historical shipments spanning the maximum expected age reached by any lamp, a_{max} :

$$F_{IRL}(y) = \sum_{v=y-a_{max}}^{y-1} P_R(y-v) s_{IRL}(v)$$

Eq. 11.17

Where:

$F_{IRL}(y)$ = failures of IRLs in year y (number of units),
 y = current year,
 v = vintage, or year of shipment,
 a_{max} = maximum expected lamp lifetime (yr),
 $P_R(y-v)$ = probability of lamp failure in year $a=y-v$ of a lamp's lifetime, and
 $s_{IRL}(v)$ = shipments that occurred in a particular vintage (number of units).

DOE uses the equations just defined, along with historical shipments data, to compute the lamp failures that require replacement in each year. The lumen capacity demand that must be met to replace these failed lamps is then:

$$D_{F,IRL}(y) = F_{IRL}(y)\Lambda C_L \quad \text{Eq. 11.18}$$

Where:

$D_{F,IRL}(y)$ = lumen capacity demand to replace failed lamps in year y (lm),
 $F_{IRL}(y)$ = lamp failures in year y (number of units),
 Λ = reference lumen output for IRL (lm/unit), and
 C_L = a lifetime correction factor.

The lifetime correction factor is given by $C_L = \max(L, 1)$, where L is the lamp lifetime in years (Eq. 11.16). It is necessary to account for lamps with average lifetimes shorter than one year, which will yield multiple shipments per fixture per year that will not be operated simultaneously. The total lumen demand is then

$$D_{IRL} = D_{NCR,IRL} + D_{F,IRL} \quad \text{Eq. 11.19}$$

Where:

$D_{NCR,IRL}$ = the demand for IRLs in new construction and renovations, given by Eq. 11.12.

Fluorescent Ballast Retirement. To compute the demand associated with the replacement of retired ballasts, DOE follows the ballast retirement model used in the 2011 fluorescent ballast rulemaking¹¹. The probability of a ballast's retirement from the stock during year a_B of its lifetime is described by a Weibull distribution:

$$P_{BR}(a_B) = w_R(a_B) \quad \text{Eq. 11.20}$$

Where:

$P_{BR}(a_B)$ = the probability that a ballast retires from the stock in the a_B^{th} year since its installation,
 $w_R(a_B)$ = the Weibull retirement distribution given in Eq. 11.14, and
 a_B = the ballast's age (yr).

The probability that a ballast survives to be a_B years old is also described by the appropriate Weibull function:

$$P_{BS}(a_B) = w_S(a_B) \quad \text{Eq. 11.21}$$

Where:

$P_{BS}(a_B)$ = the probability that a ballast survives for a_B years after installation,
 $w_S(a_B)$ = the Weibull survival distribution given in Eq. 11.13, and
 a_B = the ballast's age (yr).

For ballasts, DOE used a retirement and survival probability defined as a function of ballast age, rather than hours of use as for lamps, for consistency with the 2011 fluorescent

ballast rulemaking analysis. In that analysis, DOE used the sector-specific model parameters given in Table 11.2.3, which are the same model parameters used for the present analysis. To model the commercial and industrial sectors jointly in this analysis, DOE used a weighted average of the parameters for the commercial and industrial sector when modeling each lamp type, according to the relative distribution of each type among the two sectors, as given in Table 4.1 of DOE's 2010 Lighting Market Characterization (LMC).¹³

The retirement model for ballasts was developed in the ballast rulemaking from studies that measured the actual lifetimes of fluorescent ballasts in the field. Thus, DOE assumed that it includes the effect both of ballasts that fail and of ballasts that are retired for retrofits and renovations. The number of ballasts that are removed from the stock due to failures, retrofits, and renovations for each ballast option in each year is given by:

$$F_B(y) + R_B(y) = \sum_{v=y-a_{B,max}}^y P_{BR}(y-v) s_B(v)$$

Eq. 11.22

Where:

$F_B(y)$ = ballast failures in year y for ballast option B (number of units),
 $R_B(y)$ = ballasts retiring in year y for ballast option B due to retrofits or renovations (number of units),
 y = the model year,
 v = the vintage, or year of shipment,
 $a_{B,max}$ = the maximum expected ballast age for ballast option B (yr),
 $s_B(v)$ = shipments of ballast option B in vintage year v (number of units), and
 $P_{BR}(y-v)$ = probability of retirement in or before year $y-v$ of the lifetime of ballast option B , as defined in Eq. 11.20.

Because renovations are already accounted for as a fixed fraction of the total stock in the computation of D_{NCR} (Eq. 11.12), this portion of the demand must be subtracted from the total demand for replacing retired ballasts to yield the total demand for replacing failed ballasts within each ballast option:

$$D_{B,F}(y) = [F_B(y) + R_B(y) - S_B(y-1)f_{ren}] \Lambda_B$$

Eq. 11.23

Where:

$D_{B,F}(y)$ = the lumen demand resulting from failed ballasts in year y from ballast option B (lm),
 Λ_B = the reference lumen output produced by a system consisting of the reference ballast for the ballast technology of ballast option B , coupled to the average number of lamps for that technology having the reference lumen output for the lamp type being considered (lm/unit),
 $S_B(y-1)$ = stock of ballasts of option B being considered in year $y-1$ (number of units) (Eq. 11.40), and
 f_{ren} = fraction of the stock retired for renovations in each year.

The reference lumen output for each ballast technology, Λ_B is derived from the reference lamp and ballast properties summarized in section 11.3.6.4 using the following equation:

$$\Lambda_B = \Lambda_l \times BF_B \times \bar{n}_{lamp,B} \quad \text{Eq. 11.24}$$

Where:

Λ_l = the mean lumen output of lamp option l ,

BF_B = the ballast factor of ballast option B , and

$\bar{n}_{lamp,B}$ = the average number of lamps per ballast for ballast option B .

GSFL Retirement. As is the case with IRLs, the GSFL survival function depends on the GSFL Weibull retirement function, Eq. 11.14, which in turn depends on the characteristic lamp lifetime, T . In the case of IRLs, lamp lifetimes were corrected for the effect of lighting controls, before being utilized in the Weibull function. In the case of GSFLs, the effect of lighting controls is different and more complicated. Increased use of lighting capacity under lighting controls in the commercial and industrial sectors has the effect of shifting lighting systems to programmed start ballasts more rapidly, because fluorescent lighting control systems generally include these ballasts. GSFLs operating on programmed start ballasts tend to last longer than those operating on instant start ballasts. Other effects of lighting controls include increased lamp lifetime due to decreased operating hours as well as decreased lamp lifetimes due to increased switching for on-off type controls. DOE assumes the net effect of these two changes approximately cancel out, so DOE considers only the lamp lifetime increase caused by the programmed start ballast itself. This requires no adjustment of GSFL lifetimes obtained from the engineering analysis (chapter 5 of this TSD) for the shipments modeling, given that the model explicitly addresses the shift to programmed-start ballasts caused by controls, and the model then selects the lamp lifetime appropriate to the ballast it is coupled with (see Table 11.3.9).

DOE believes that a certain fraction of GSFLs in the commercial and industrial sector are subject to scheduled group relamping, in which all lamps within a space are replaced simultaneously when they have reached a predetermined fraction of their rated lifetime (in hours). DOE assumed that group relampings occur, on average, when lamps reach 85% of their rated lifetime. To account for this effect, DOE computed the characteristic lamp lifetime by adjusting the GSFL life hours in chapter 5 of this TSD, according to the following equation.

$$T = T_{Rated}(1 - 0.15f_{GR}) \quad \text{Eq. 11.25}$$

Where:

T_{Rated} = the rated lamp lifetime, in hours, and

f_{GR} = the fraction of lamps that are subject to group relamping.

DOE used the group relamping fractions reported in the 2011 ballast rulemaking¹¹ for this analysis. To simplify the model, DOE also assumed that, for each ballast technology, all lamps coupled to that ballast have the same rated lifetime, T_{Rated} , and that this is given by the

lifetime of the baseline lamp option, which was taken to be representative of all lamps in the lamp type.

DOE used the ballast shipments and stock projections as the basis to compute the shipments and stock of GSFLs. To do this, DOE developed a relamping schedule, $P_{relamp}(a_B)$, which represents the probability that a ballast has a new lamp installed when it is a_B years old (provided that it survives to that age). DOE assumes that old lamps are discarded upon ballast retirement so that all new ballasts are coupled with new lamps when they are installed. This implies that $P_{relamp}(0) = 1$: that is, there is a 100% probability in the model that a ballast has a new lamp installed when it is first installed.

For $a_B > 0$, the probability of ballast relamping depends on the probability of lamp failure in the h_B th hour of the ballast's operation. The relamping probability also depends on the annual hours of lamp use, u , and on the average number of hours, η , that the lamp is operated each time it is started, as GSFLs that are switched on and off more frequently have degraded lifetimes. For a set of discrete usage patterns across a given sector, the lamp failure probability in each year of the ballast life is:

$$P_{relamp}(a_B) = \begin{cases} \sum_q P'_{relamp}(a_B u_q | \eta_q) f_q, & a_B > 0 \\ 1, & a_B = 0 \end{cases} \quad \text{Eq. 11.26}$$

Where:

$P_{relamp}(a_B)$ = the probability that a ballast is relamped when it is a_B years old,
 q = an index specifying a particular lighting application with a particular usage pattern,
 u_q = the average annual hours of lamp use for application q (hr),
 η_q = the average hours of use per lamp start for application q (hr),
 f_q = the fraction of all lumen demand associated with application q ,
 a_B = the number of years since the ballast's installation (yr), and
 $P'_{relamp}(a_B u_q | \eta_q)$ = the conditional probability that a ballast is relamped in hour
 $h_B = a_B u_q$ of its operation, given an average of η_q hours of use per start.

DOE used the distribution of usage hours from the LCC analysis (chapter 8 of this TSD) to determine u_q and f_q . For each application q , DOE also specified an average hours of use per start, η_q , based on industry estimates. The hours-per-start values used in this analysis are given in Table 11.3.19, Table 11.3.20, and Table 11.3.21

The probability of relamping as a function of the ballast's operating hours, given its usage pattern, can be computed by summing over the probability that the ballast undergoes its n th relamping, for all values of n :

$$P'_{relamp}(h_B|\eta) = \sum_n P_{relamp,n}(h_B|\eta)$$

Eq. 11.27

Where:

$P_{relamp,n}(h_B|\eta)$ = the conditional probability that the ballast has its n th relamping in hour h_b of its operation, given that it is burned for η hours per start, h_B = the number of hours that the ballast has been operated (hr), and all other parameters are defined as in Eq. 11.26.

The sum in Eq. 11.27 is formally an infinite sum, but in practice it is sufficient to compute the first few terms of the sum (corresponding to the first few relampings) over a domain limited to the maximum expected ballast lifetime in hours. The sum can then be truncated; adding extra terms has a negligible impact on the probability computed over that domain, since the probability of the n th relamping's occurring before the ballast fails shrinks rapidly as n increases.

The probability of the n th relamping can be defined recursively from the probability of an individual lamp's retirement as a function of each individual lamp's operating hours and the average number of hours per start, $P_{LR}(h_L|\eta)$. The probability of the first relamping on a ballast is just equal to this distribution evaluated at $h_L = h_B$:

$$P_{relamp,1}(h_B|\eta) = P_{LR}(h_B|\eta)$$

Eq. 11.28

Where:

$P_{LR}(h_B|\eta)$ = the probability that a lamp retirement occurs in hour $h_L = h_B$ of the lamp's lifetime (specified below).

The probability of the n th relamping can then be computed recursively for $n > 1$ using the following equation:

$$P_{relamp,n}(h_B|\eta) = \sum_{h'_B=0}^{h_B} P_{LR}(h'_B|\eta) P_{relamp,n-1}(h_B - h'_B|\eta)$$

Eq. 11.29

Where:

all parameters are defined as in the previous equations.

DOE modeled the lamp retirement probability in the above equations as a Weibull distribution whose characteristic lifetime parameter depends on the usage pattern:

$$P_{LR}(h_L|\eta) = w_R(h_L; T(\eta))$$

Eq. 11.30

Where:

$P_{LR}(h_L|\eta)$ = the probability of a lamp's retirement in year h_L of its operation (given that its ballast survives that long),

$w_R(h_L; T(\eta))$ = the Weibull retirement function (Eq. 11.14), where the dependence on the characteristic lifetime T has been made explicit,

h_L = the number of hours that the lamp has been operated (hr), and

$T(\eta)$ = the characteristic lifetime parameter of the Weibull distribution, which depends on η , as described below.

DOE determined the parameters of this distribution from the lamp failure curves published in chapter 6 of the Lighting Handbook¹⁴, obtaining the values of k and λ given in Table 11.2.3. DOE also determined the scaling of lamp lifetime with η from the same published curves. The characteristic lifetime $T(\eta)$ is given by scaling the rated lamp lifetime by a scaling factor that depends on η . Assuming that the rated lamp lifetime reported by manufacturers corresponds to $\eta=3$ hours per start, the scaling of lamp lifetime to different values of η is tabulated in Table 11.2.4. Combining the previously defined equations, it is possible to compute the relamping schedule $P_{relamp}(l_B)$ from Eq. 11.26.

Table 11.2.4 Scaling of Lamp Lifetime with Average Hours of Lamps Use per Start

Average burn hours per lamp start	Lamp mean lifetime as a percentage of the nominal lifetime
0.1	24
0.2	38
0.3	45
0.4	50
0.5	54
0.6	58
0.7	61
0.8	64
1	70
2	89
3	101
4	110
5	116
6	121
7	125
8	129
10	134
20	149
30	156
40	159
60	161
100	162

The equations above, with some minor modifications, can also be used to derive the average lamp lifetime, measured in years, after accounting for the various usage patterns present in the stock and assuming that the ballast survives throughout the lamp's life:

$$L_L = \sum_{a_B=0}^{\infty} a_B P_{1st\ relamp}(a_B)$$

Where:

L_L = the average lifetime of a GSFL, in years, assuming that its ballast does not fail during the lamp's life, and

$P_{1st\ relamp}(a_B)$ = the probability that a ballast undergoes its first relamping in year a_B of its life, which can be computed from Eq. 11.26, with the substitution of $P_{relamp,1}$ (Eq. 11.28) for P'_{relamp} .

Fluorescent Lamp and Ballast Joint Survival Probability. The relamping schedule depends on the probability P_{LR} that a given lamp is retired, provided that its ballast survives. For some applications in this preliminary analysis it will be necessary to know the total probability that a lamp survives to a given age, without either failing or being retired because its ballast is being replaced. This probability depends on the ballast lifetime model and on the probability that a lamp is installed on a ballast of a particular age. It is derived below.

The probability that a particular lamp is installed on a ballast that is in year a_B of its life is:

$$P_{LIB}(a_B) = \frac{1}{\mathcal{N}_{LIB}} P_{relamp}(a_B) P_{BS}(a_B)$$

Eq. 11.31

Where:

$P_{LIB}(a_B)$ = the probability that a lamp is installed on a ballast when the ballast is a_B years old,

$P_{relamp}(a_B)$ = the probability that a ballast is relamped in year a_B of its life, provided that it survives that long,

$P_{BS}(a_B)$ = the probability that the ballast survives to age a_B (Eq. 11.21),

a_B = the age of the ballast (yr), and

$\mathcal{N}_{LIB}$ = a normalization factor that ensures that this quantity sums to unity.

The probability that a lamp's ballast is retired in year a_L of the lamp's life is then:

$$P_{BRL}(a_L) = \frac{1}{\mathcal{N}_{BRL}} \sum_{a'_L=0}^{L_{B,max}} \sum_{a_B=a'_L}^{L_{B,max}} P_{BR}(a_B) P_{LIB}(a_B - a'_L)$$

Eq. 11.32

Where:

$P_{BRL}(a_L)$ = the probability that a lamp's ballast is retired in year a_L of the lamp's life,

$P_{BR}(a_L)$ = the probability that a ballast retires in year a_B of its life (Eq. 11.20),

a_L = the age of the lamp (yr),

$L_{B,max}$ = the maximum ballast lifetime (yr), and

$\mathcal{N}_{BRL}$ = a normalization factor that ensures that this quantity sums to unity.
All other variables are as in Eq. 11.31.

The previous distribution can be combined with the lamp retirement and survival probability distributions to give the approximate^e probability that a lamp or its ballast are retired in year a_L of the lamp's lifetime:

$$P_{LBR}(a_L) = \frac{1}{\mathcal{N}_{LBR}} \left[P_{BRL}(a_L) P_{LS}(a_L) + P_{LR}(a_L) \left(1 - \sum_{a'_L=0}^{a_L} P_{BRL}(a'_L) \right) \right] \quad \text{Eq. 11.33}$$

Where:

$P_{LBR}(a_L)$ = the probability that a lamp or its ballast is retired in year a_L of the lamp's lifetime,
 $P_{LS}(a_L)$ = the probability that a lamp survives to age a_L ,
 $P_{LR}(a_L)$ = the probability that a lamp is retired in year a_L of its life,
 $\mathcal{N}_{LBR}$ = is an appropriate normalization parameter, and
all other parameters are as in Eq. 11.32.

The average lamp lifetime and the probability that a lamp and its ballast both survive to lamp age a_L are then simply given by summing over the retirement probability:

$$L_{LB} = \sum_{a_L=0}^{\infty} a_L P_{LBR}(a_L) \quad \text{Eq. 11.34}$$

$$P_{LBS}(a_L) = 1 - \sum_{a'_L=0}^{a_L} P_{LBR}(a'_L) \quad \text{Eq. 11.35}$$

Where:

L_{LB} = the average lifetime of a GSFL, in years, accounting for the probability that either the lamp or its ballast retires.
 $P_{LBS}(a_L)$ = the probability that a lamp and its ballast both survive to the end of year a_L of the lamp's life, and
all other parameters are as in Eq. 11.33.

^e Eq. 11.32 is only approximately correct, because it does not account for the growth of the ballast stock over the summation period. However, as this computation only feeds into the calculation of the stock fractions represented by different technologies, this approximation is sufficient, given that these fractions do not change rapidly during the analysis period.

The latter probability appears again in Eq. 11.55 which apportions the lamp stock among the various efficiency levels.

11.2.2.3 Incandescent Reflector Lamps: Turnover and Shipments

Because the three different lamp options considered for IRLs have significantly different lifetimes, it was necessary to explicitly model the shipments for each IRL lamp option separately. Additionally, because of the different usage patterns in each sector, DOE modeled lamps separately in the residential and commercial sectors.

DOE computes the total lumen demand for each lamp option separately within each sector, according to Eq. 11.8, Eq. 11.12, and Eq. 11.18. DOE then reallocates this demand among the three lamp options using the consumer choice module, yielding a projection for the shipments of each lamp option in each year:

$$s_{IRL,l}(y) = \Lambda^{-1} \sum_k D_k(y) \sigma_{kl}(y)$$

Eq. 11.36

Where:

$s_{IRL,l}(y)$ = projected shipments for IRL option l in year y (number of units),
 D_k = the total lumen demand for lamp option k , which is the sum of the demand for replacements and new construction (lm),
 Λ = maximum lumen output of the reference lamp (lm/unit), and
 $\sigma_{kl}(y)$ = the substitution matrix in year y .

The substitution matrix, σ_{kl} , specifies the fraction of consumers who switch between the lamp options, according to the consumer choice model:

$$\sigma_{kl}(y) = \frac{C_{L,l}}{C_{L,k}} P_{kl}(z) A_{kl}(y)$$

Eq. 11.37

Where:

$C_{L,k}$ = lifetime correction factor for lamp k , as defined after Eq. 11.18,
 $C_{L,l}$ = lifetime correction factor for lamp l ,
 P_{kl} = probability of purchasing lamp option l from among the available lamp options, given that option k is being replaced, and
 $A_{kl}(y)$ = availability matrix.

The availability matrix $A_{kl}(y)$ specifies the products that are available to a consumer who is replacing a failed lamp of lamp option k : it is zero when lamp option l is not a direct substitute for k , or when lamp option l has been eliminated by a proposed standard in the standards case; it is equal to unity otherwise. In the case of IRLs, all lamp options being considered are directly interchangeable, so, within each sector, $A_{kl}(y) = 1$ for all l except those that would be eliminated by a proposed standard. The choice probability $P_{kl}(z)$ is the probability of purchasing lamp option

l from among the available lamp options, given that lamp k is being replaced, according to the consumer choice module described in section 11.3.

As also described in section 11.3, the logit z depends linearly on the first costs and the annual O&M costs of the available lamps. It is thus an implicit function of time, because the product price varies in each year according to the learning model, starting from the prices determined for the year 2011 in the engineering analysis, and the energy costs vary according to the *AEO 2013*² forecast. The lamp first costs FC_l are given by the learning-corrected lamp price, computed from Eq. 11.4 and Eq. 11.5, plus sales tax and the labor cost for installation determined in the LCC analysis. The O&M costs for IRLs have two components: energy costs and the relative relamping costs, averaged annually, for lamps with different lifetimes:

$$OM_l(y) = p_E(y)W_l\bar{u} + \left[\frac{1}{L_l} - \frac{1}{\max(\{L_k\})} \right] FC_l \quad \text{Eq. 11.38}$$

Where:

OM_l = the O&M costs of lamp option l (\$/yr),
 FC_l = the first cost of lamp option l (\$),
 $p_E(y)$ = the sector-specific price of electricity, in year y , as forecast in the *AEO2013* reference scenario^f (\$/kWh),
 W_l = the national-average wattage of lamp option l (W),
 $\bar{u}$ = average annual hours of use in the sector being considered (hr),
 L_l = the average lifetime of lamp option l (yr), and
 $\max(\{L_k\})$ = the maximum lifetime of all lamp options (yr).

For years beyond the end of the *AEO* projection, which was in 2040, DOE extrapolated $p_E(y)$ from the trend in the period from 2030 to 2040, through 2060, and held prices constant thereafter. While for the shipments analysis electricity prices are relevant only through the end of the shipments analysis period in 2046, a longer analysis period is required for the NIA, as described in chapter 12 of this TSD. As discussed in section 11.2.2.3, DOE considers that some fraction of IRLs is installed on dimmers. Since the use of dimmers will affect operating wattages of IRLs, DOE adjusted the rated wattage of each IRL option downward by a factor of 6% and 1% in the residential and commercial sectors, respectively, to account for typical dimming rates and the fractions of lamps that are installed on dimmers in each sector.

DOE used the model above to project the shipments of each IRL option in each year of the analysis. The input parameters, and their calibration, are discussed in section 11.3.4. Given

^f Some model scenarios for the NIA in chapter 12 of this TSD use the High- or Low-Economic-Growth *AEO* forecasts for electricity price. In principle, the shipments analysis should also use these forecasts in such cases, because the different electricity prices will impact the consumer choice model. However, DOE performed a sensitivity analysis using the different *AEO* forecasts in the shipments model and found negligible impact on the projected shipments. DOE, therefore, chose to use only the reference *AEO* scenario in the shipments analysis, regardless of the electricity price forecast selected for the NIA.

the projections of failures, renovations, and new shipments in each year, and a calculation of the total operating stock in the initial year of the analysis period, Eq. 11.9 then yields the total operating stock of IRLs in the United States in each subsequent year. DOE also uses that equation to compute the OSSDAP (as described in the text following Eq. 11.9) as an input for computing the NES in the NIA (chapter 12 of this TSD).

11.2.2.4 General Service Fluorescent Lamps: Turnover, Consumer Choice, and Shipments

As discussed previously, DOE took a two-stage approach to projecting GSFL shipments, first by projecting the shipments and stock of fluorescent ballasts, then using this projection as a basis to project lamp shipments. This approach led to a few complications to the consumer choice model used to compute lamp turnover. For example, if the consumer is purchasing a new lamp-and-ballast system for a lighting renovation or new construction, the choice will depend on the first cost and O&M cost of the lamp-and-ballast system, with the O&M cost also including the price of replacement lamps; but, if the consumer is purchasing only a replacement lamp, the lamp price will be included in the first cost and not the O&M cost. An additional complication also arises because the GSFL category includes multiple lamp types, so the consumer choice model must apportion lumen demand among these lamp types in addition to the different efficiency levels (*i.e.*, lamp options) within each lamp type. To address these issues, DOE treats the choice of lamp type, ballast option, and lamp option (efficiency level) as independent choice events in the consumer choice model. Since the different GSFL lamp types are not interoperable on the same ballast, DOE assumes in the shipments analysis that a consumer's choice of a lamp type, ballast technology, and ballast factor occurs when choosing a new lamp-ballast system during a retrofit, renovation, or new construction; while the choice of a lamp option (efficiency level) occurs whenever the consumer chooses a lamp to couple to a new or existing ballast.

Each lamp type in the model is associated with a few representative ballast options that were developed from the set of ballasts considered in the LCC analysis (chapter 8 of this TSD). For each lamp type, the associated ballasts include one or more non-dimmable ballast technologies that are either instant start or programmed start, depending on which ballast technologies were considered in the LCC. Where the LCC considered ballasts with different ballast factors, the shipments analysis and NIA include one representative normal ballast-factor option and one representative low ballast-factor option within each ballast technology, drawn from the ballasts considered in the LCC. For lamp types that have dimming ballasts available in the LCC, DOE also considered a separate dimmable ballast option, in addition to the non-dimming ballasts just described.

The representative ballast options used in the shipments analysis are summarized in Table 11.3.9 and Table 11.3.10. In the shipments analysis, DOE computed the turnover and shipments of ballasts for each of these representative ballast options as a proxy for the wider array of ballast options available on the US market. As mentioned above, DOE then computed the shipments of GSFLs necessary to maintain functional lamps on the installed stock of these ballasts, which yields a projection of GSFL shipments over the analysis period.

Ballast Shipments. DOE used a ballast turnover model that is broadly similar in concept to the turnover model for IRLs developed in section 11.2.2.3, but there are significant differences in the details. The turnover model tracks the shipments and stock of ballasts within each of the individual ballast options considered in the analysis (these are summarized in Section 11.3.6.2). In each year of the model, DOE first determined the demand for new ballast shipments according to Eq. 11.8, Eq. 11.12, and Eq. 11.23. DOE then apportioned this demand among the available lamp types, and their associated ballast technologies, and ballast options, in two ways.

First, DOE assumed that, when ballasts are replaced due to equipment failure, they are replaced with a ballast of the same type and the same ballast factor. Second, in the case of new construction and renovations, DOE allocated the shipments among the different lamp types and ballast options using the consumer choice module, modulated by assumptions about the growth of lighting controls.

Thus, the total shipments of ballast option B , are given by:

$$s_B(y) = s_{B,F}(y) + s_{B,NCR}(y) \quad \text{Eq. 11.39}$$

Where:

$s_{B,j}(y)$ = the shipments of ballast option B , in year y (number of units),

$s_{B,F}(y)$ = the shipments of ballast option B that are installed to replace failed ballasts in year y , and

$s_{B,NCR}(y)$ = the shipments of ballast option B that are installed in new construction, retrofits, and renovations in year y .

The first term in Eq. 11.39 is simply given by the assumption that consumers with failed ballasts simply replace them in kind with the same ballast option:

$$s_{B,F}(y) = \frac{D_{B,F}(y)}{\Lambda_B} \quad \text{Eq. 11.40}$$

Where:

$D_{B,F}(y)$ = the lighting capacity demand for replacements of failed ballasts of option B , as defined in Eq. 11.23, and

Λ_B = the mean lumen output of ballast option B , as defined in Eq. 11.24, when coupled to a lamp with the reference properties detailed in section 11.3.6.4.

The second term in Eq. 11.39 is determined by the consumer choice module, which apportions shipments for new construction, renovations, and retrofits among the different lamp types and ballast options. These shipments of ballast option B , which is within ballast technology T associated with lamp type j are given by:

$$s_B(y) = P_{(T|j)}(y) \sum_c P_{(c|T,j)}(y) P_{(B|T,j,c)}(y) \sum_i \frac{D_{NCR,i}(y) \sigma_{ij}^{(c)}(y)}{\Lambda_{B,i}(y)}$$

Eq. 11.41

Where:

$P_{(T|j)}(y)$ = the probability in year y that a consumer utilizes ballast technology T , given that the consumer has a lighting system utilizing lamp type j .

c = an index representing one of three possible types of lighting controls systems (including no controls),

$P_{(c|T,j)}(y)$ = the probability in year y that a consumer has controls of type c given that the consumer utilizes ballast technology T and lamp type j ,

$P_{(B|T,j,c)}(y)$ = the probability in year y that a consumer chooses ballast option B , given that the consumer utilizes ballast technology T and lamp type j and has lighting control type c ,

$D_{NCR,i}(y)$ = the lighting capacity demand for ballasts associated with lamp type i in new construction, retrofits, and renovations in year y , as defined in Eq. 11.12 (lm),

$\Lambda_{B,i}(y)$ = the reference lumen output of a lamp-ballast system incorporating lamp type i in year y , as defined in Eq. 11.24, using the reference assumptions detailed in section 11.3.6.4(lm/unit), and

$\sigma_{ij}^{(c)}(y)$ = the substitution matrix between lamp types i and j for a consumer implementing controls of type c .

In the above equation, the control type index c may take on three values: NC , for no controls; DC , for dimming controls; and SC , for switching-only controls (*i.e.*, controls without a dimming ballast).

The first two probabilities in Eq. 11.41 are not determined by the consumer-choice logit model, because DOE believes that the choice of ballast technology and control system is heavily application-dependent and is not well described by a purely cost-based model. Instead, DOE determined these probabilities from an exogenous model it developed for the growth of lighting controls in commercial buildings over the analysis period. That model, which is summarized in appendix 11A, projects the fraction $f_c(y)$ of commercial floorspace that is implementing automated lighting controls in each year of the analysis.

To apportion ballast shipments to the dimming ballast technology, DOE assumed, based on data in the *2010 Lighting Market Characterization*¹³ combined with assumptions about the fraction of each control type that relies on a dimming ballast, that 26% of GSFL lighting control systems include dimming ballasts. Thus, DOE assumed that $P_{(T=Dimming|j)} = 0.26f_c(y)$ for all lamp types j . For all lamp types other than 4-foot MBP, there is only one non-dimming ballast technology, so the probability of this technology's being utilized is simply the complement of the dimming-ballast probability. For the 4-foot MBP lamp type, both instant-start and programmed-start non-dimming ballast technologies are available. To apportion ballasts between these technologies, DOE noted that switching-only controls systems are likely to utilized programmed-start ballasts, since the adverse impact of rapid switching on lamp lifetime is lessened for such

systems. DOE is also aware that some switching-only controls systems will utilize instant-start ballasts, but DOE believes that this configuration is unlikely to experience significant growth in the future. Therefore, to apportion 4-foot MBP ballast shipments among the non-dimming ballast technologies, DOE assumed that programmed start ballasts make up all ballasts coupled to switching-only controls whose use is driven by compliance with state building codes (section 11A.1.2.1). DOE further assumed that instant start ballasts make up all ballasts without controls, as well as all ballasts coupled to switching-only controls whose use is driven by other factors than state building codes (section 11A.1.2.2).

The second probability in Eq. 11.41, that a consumer with a particular ballast technology has a particular type of controls system, is now straightforward to compute. For consumers with dimming ballasts, the probability of having non-dimming controls is zero, and the probability of having dimming controls is unity. For consumers with non-dimming ballasts, the probability of having switching controls is equal to the fraction of non-dimming systems with either switching controls or no controls, both of which can be readily computed from the same considerations discussed in the previous paragraph.

The remainder of Eq. 11.41 is computed via two applications of the consumer-choice logit model described in Section 11.2.1.2. The first such application determines the probability that a consumer chooses ballast option B from among the options within a particular ballast technology:

$$P_{(B|T,j,c)} = P_B(z_{T,j,c}) \quad \text{Eq. 11.42}$$

Where:

P_B = the probability of selecting ballast option B from within all available options in technology T for lamp type j (Eq. 11.1),

$z_{T,j,c}$ = the logit variable (defined in Eq. 11.2 and explicated below) for a consumer utilizing ballast technology T for lamp type j with controls of type c , which is an implicit function of the year y , as shown below.

The second application of the logit model computes the substitution matrix for the lamp types, σ_{ij} . This is similar to the one defined for IRLs in Eq. 11.37, but no lifetime correction factors are required, since all ballasts are assumed to last longer than a year on average. In this case, however, the substitution matrix must include a correction for the relative light output of the reference system in each lamp type. DOE assumed in this analysis that consumers purchasing lamp-ballast systems utilizing different lamp types during retrofits, renovations, and new construction, may install different numbers of lamps per square foot of floor space, in order to maintain roughly equivalent light levels. The substitution matrix for ballasts is thus given by:

$$\sigma_{ij}(y) = \frac{\Lambda_{B,i}}{\Lambda_{B,j}} P_{ij}(z_{ij,c}) A_{ij}(y) \quad \text{Eq. 11.43}$$

Where:

$\Lambda_{B,i}$ = the reference lumen output of ballast option B , associated with lamp type i , as defined in Eq. 11.24, using the reference assumptions detailed in section 11.3.6.4
 P_{ij} = the probability of choosing lamp type j from among all available lamp types, given that a system utilizing lamp type i is being replaced (Eq. 11.1),
 $z_{ij,c}$ = the logit variable (defined in Eq. 11.2 and explicated below), for a consumer who has controls of type c and is substituting lamp type j for lamp type i , which is an implicit function of y as shown below, and
 $A_{ij}(y)$ = the availability matrix of lamp types.

The availability matrix for lamp types in the ballast turnover model defines whether or not a system of lamp type j can be considered a substitute for a system of lamp type i . This matrix is fixed throughout the analysis period, and, unlike in the case of lamps, it does not change between the base case and the standards cases, since the candidate standard levels analyzed here will not eliminate any entire lamp types. Table 11.3.7 summarizes the lamp type substitutions that are available in the ballast choice model.

The purchase probabilities P_B and P_{ij} in Eq. 11.42 and Eq. 11.43 are determined from the logit z for each purchase decision. The logit depends on the first costs and O&M costs of the lamp-and-ballast systems being considered, as explained in section 11.2.1.2. The first cost for a lamp-and-ballast system is given by^g:

$$FC_{BL}(y) = p_B(y) + I_B + \bar{n}_{lamp,B}p_L(y) + I_L \quad \text{Eq. 11.44}$$

Where:

$FC_{BL}(y)$ = the total first cost of a lamp-ballast system consisting of ballast B and lamp L in year y (2012\$),
 $p_B(y)$ = the purchase price of the ballast in year y (2012\$), including corrections for learning, as computed using Eq. 11.4 and Eq. 11.5,
 I_B = the installation cost of the ballast (2012\$),
 $\bar{n}_{lamp,B}$ = the average number of lamps installed on ballast option B (summarized in section 11.3.6),
 $p_L(y - 1)$ = the purchase price of the lamp in year y (2012\$), including corrections for learning and any rare-earth price scenario corrections, as defined in appendix 11B, and

^g DOE did not include the cost of purchasing or installing lighting fixtures when computing the first costs of lamp-ballast systems. DOE believes that comparable fixtures are available for comparable costs for different lamp types and that the selection of a particular fixture is complex and is generally driven more by aesthetic considerations than economic ones. Where price components are equal between lamp types, the inclusion of those components will not affect the outcome of the model; therefore DOE excluded fixture costs from explicit consideration in the logit model.

I_L = the cost to install $n_{lamp,B}$ lamps on ballast B .

The O&M costs associated with a lamp-ballast system in the choice model are given by the mean fuel costs associated with powering the lamp-and-ballast system, as well as the first costs of the new lamps required to relamp the ballast over its lifetime:

$$OM_{BL}(y) = \frac{p_E(y)\bar{u}}{1000}SIP_{BL} + \bar{n}_{lamp,B}\bar{n}_{relamp,B}p_L(y) \quad \text{Eq. 11.45}$$

Where:

$OM_{BL}(y)$ = the operation and maintenance costs in year y for a lamp-ballast system consisting of ballast B and lamp L (2012\$/yr),
 $p_E(y)$ = the price of electricity in year y (2012\$/kWh),
 SIP_{BL} = the average system input power of the lamp-ballast system (W),
 $\bar{u}$ = the average annual hours of use in the sector being considered, computed using the assumptions in section 11.3.6.6 (hrs),
 $\bar{n}_{relamp,B}$ = the average number of relampings that occur over the lifetime of ballast option B , and
all other variables are as defined in Eq. 11.44.

The following paragraphs discuss the details of the values used as inputs to Eq. 11.44 and Eq. 11.45. As discussed in section 11.3.6.4, when considering a consumer choice of ballast option or lamp type, DOE used reference ballast and lamp properties to represent each option in the choice set. Thus, the lamp prices and system input power in Eq. 11.44 and Eq. 11.45 are the prices of the least efficacious full-wattage lamp that has 100% acceptance as an option to be installed within the ballast option or lamp type under consideration, for the TSL being considered at that point in the analysis. Additionally, when a consumer is choosing between lamp types, the ballast prices and system input power are computed using the properties of reference ballasts chosen using the criteria laid out in section 11.3.6.4.

In either case, the system input power is given by the following formula

$$SIP_{BL} = RAP_l \times BF_B \times \bar{n}_{lamp,B} \times 100/BLE_B \quad \text{Eq. 11.46}$$

Where:

RAP_l = the reference arc power of lamp option l (W),
 BF_B = the ballast factor of ballast option B ,
 $\bar{n}_{lamp,B}$ = the average number of lamps per ballast for ballast option B , and
 BLE_B = the ballast luminous efficacy of ballast option B .

The inputs to this formula are detailed in section 11.3.6.

As discussed following Eq. 11.36, DOE used the sector-specific *AEO 2013* forecasts for electricity prices, extrapolated to years beyond 2040. For ballast options that were analyzed in

the commercial and industrial sectors jointly, DOE used a weighted average of those sectors' price forecasts, based on the fraction of each lamp type found in the stock estimates from DOE's 2010 *Lighting Market Characterization* (LMC).¹³ These fractions are summarized in Table 11.3.9.

The average number of ballast relampings is given by combining the relamping schedule (discussed in section 11.2.2.2) with the ballast survival probability:

$$\bar{n}_{relamp,B} = \sum_{a_B=0}^{a_{B,max}} P_{relamp}(a_B) P_{BS}(a_B) \quad \text{Eq. 11.47}$$

Where:

- $\bar{n}_{relamp,B}$ = the average number of relampings that occur on ballast option B ,
- a_B = the ballast age (yr),
- $a_{B,max}$ = the maximum expected ballast age (yr),
- $P_{relamp}(a_B)$ = the relamping schedule, or probability of ballast relamping in year a_B of the ballast's life, as defined in Eq. 11.26, and
- $P_{BS}(a_B)$ = the ballast survival probability, defined in Eq. 11.21.

DOE uses this model to project the shipments of fluorescent ballasts in each year of the analysis via Eq. 11.39. The input parameters, and their calibration, are discussed in section 11.3.4. Given the projections of failures, renovations, and new shipments in each year, and a calculation of the total operating stock in the initial year of the analysis period, Eq. 11.9 yields the total operating stock of ballasts in the United States in each subsequent year. The steps in the ballast shipments turnover model are summarized as a schematic diagram in Figure 11.2.2, which shows failed ballasts and ballasts removed for renovation leaving the stock, the allocation of demand for new construction and renovation in the consumer choice module, the compilation of the annual shipments projection, and the reallocation of some shipments to LEDs. DOE also uses that equation to compute the OSSDAP (as described in the text following Eq. 11.9) as an input for computing the NES in the NIA (chapter 12 of this TSD).

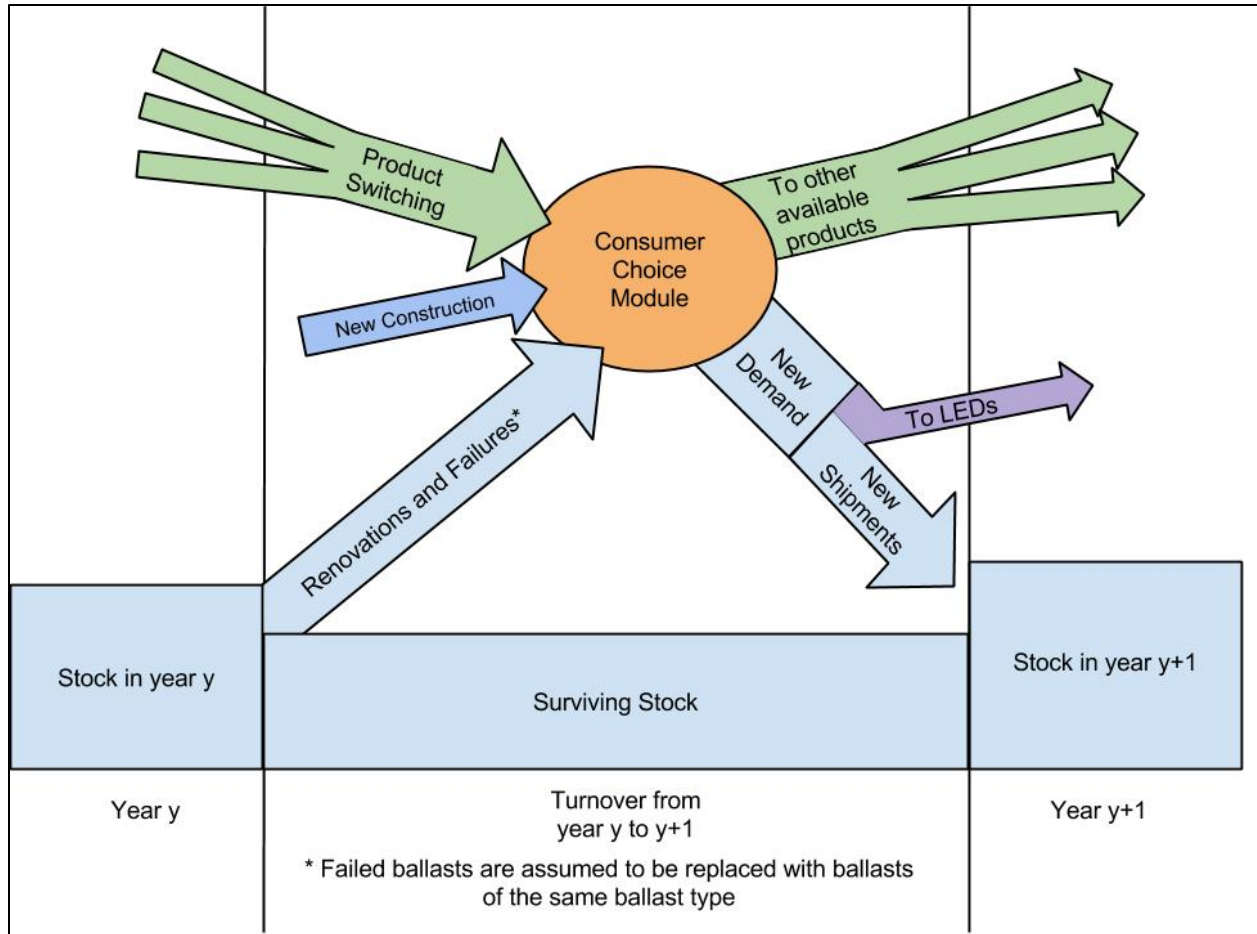


Figure 11.2.2 Schematic diagram of the annual ballast turnover for a single ballast option in the shipments model, including the effect of the consumer choice model and LED incursion.

General Service Fluorescent Lamp Shipments. After computing the shipments and stock of fluorescent ballasts, DOE projects the shipments and stock of GSFLs by combining the ballast projection with the relamping schedule defined in Eq. 11.26. The total operating stock of GSFLs in the United States is simple to compute from the total operating stock of ballasts:

$$S_{GSFL,B}(y) = S_B(y) \bar{n}_{lamp,B}$$

Eq. 11.48

Where:

$S_{GSFL,B}$ = the total operating stock of GSFLs coupled to ballasts option B in year y (number of units),

S_B = the total operating stock of ballasts of type B in year y (number of units), and

$\bar{n}_{lamp,B}$ = the average number of lamps coupled to a ballast option B .

In the context of computing the NES, however, the relevant quantity is not the total stock but the OSSDAP (described in the text following Eq. 11.9). This can be computed by adding the

stock of lamps installed on new ballasts since the rulemaking compliance year y_{rule} to the stock of lamps shipped during or after y_{rule} installed on old ballasts that were installed prior to y_{rule} :

$$S'_{GSFL,B}(y) = S'_{LONB,B}(y) + S'_{LOOB,B}(y) \quad \text{Eq. 11.49}$$

Where:

$S'_{GSFL,B}(y)$ = the OSSDAP of all GSFLs installed on ballast option B (number of units),
 $S'_{LONB,B}(y)$ = the OSSDAP of lamps on new ballasts—*i.e.*, ballasts installed in y_{rule} or later—of ballast option B (number of units), and
 $S'_{LOOB,B}(y)$ = the OSSDAP of lamps on old ballasts—*i.e.*, ballasts installed prior to y_{rule} that have had their lamps replaced since y_{rule} —of ballast option B (number of units).

The two terms on the right hand side of Eq. 11.49 can be computed from the projection of ballast shipments, the probability distribution of ballast retirement over the ballast lifetime, and the probability distribution of lamp replacement on an existing ballast over the ballast lifetime. For ballasts installed during or after the compliance year, the operating stock of lamps is:

$$S'_{LONB,B}(y) = \sum_{v=y_{rule}}^y s_B(v) P_{BS}(y-v) \quad \text{Eq. 11.50}$$

Where:

v = the vintage, or year, of ballast shipment,
 y = the model year,
 y_{rule} = the compliance year of the proposed new standards,
 $s_B(v)$ = the shipments of ballast option B in vintage year v (number of units), defined in Eq. 11.39, and
 $P_{BS}(y-v)$ = the probability of ballast survival to year $y-v$ of the ballast lifetime, defined in Eq. 11.21.

For lamps shipped in or after y_{rule} that are coupled to ballasts installed prior to y_{rule} , the OSSDAP is:

$$S'_{LOOB,B}(y) = \sum_{v=y_0}^{y_{rule}-1} s_B(v) P_{BS}(y-v) C_{relamp}(y|y_{rule}, v) \quad \text{Eq. 11.51}$$

Where:

$C_{relamp}(y|y_{rule}, v)$ = the cumulative probability that a ballast has been relamped at least once since the year y_{rule} , given that it was initially installed in the vintage year v , and
all other variables are as defined in Eq. 11.50.

The cumulative relamping probability is computed by integrating over the differential relamping probability:

$$C_{relamp}(y|y_{rule}, v) = \max \left(1, \sum_{y'=y_{rule}}^y P_{relamp}(y' - v) \right) \quad \text{Eq. 11.52}$$

Where:

$P_{relamp}(y' - v)$ = the relamping schedule, *i.e.*, the probability that a ballast shipped in vintage year v is relamped in year y' (Eq. 11.26), and all other variables are defined as in Eq. 11.51.

The projected annual shipments of GSFLs, necessary to compute the equipment costs portion of the NPV, can also be computed from the relamping probability, when combined with the ballast shipments projection:

$$s_{GSFL,B}(y) = \sum_v s_B(v) P_{relamp}(y - v) \quad \text{Eq. 11.53}$$

Where:

$s_{GSFL,B}(y)$ = the shipments of GSFLs installed on ballast option B in year y (number of units),
 $s_B(y)$ = the shipments of ballast option B in year y , defined in Eq. 11.39 (number of units), and
all other variables are defined as in Eq. 11.48, Eq. 11.49, and Eq. 11.50.

11.2.2.5 General Service Fluorescent Lamps: Market Shares and Stock Shares

To compute the projected equipment costs and energy consumption for GSFLs, it is necessary to apportion the projected shipments among the various lamp options available for each ballast option. DOE computes the market share using the consumer choice model developed in section 11.2.1.2. Consumers are assumed to be choosing from among the various lamp options that can be coupled to their installed ballasts, as discussed in section 11.3.6.1.

The market share of shipments allocated to lamp option l of lamps installed on ballast option B is given by:

$$MS_{l,B}(y) = P_{l,B}(z(y)) \quad \text{Eq. 11.54}$$

Where:

$MS_{l,B}(y)$ = the market share of lamp option l among lamps installed on ballast option B during year y ,
 y = the model year,
 $P_{l,B}(z)$ = the consumer choice probability of selecting lamp option l for installation on ballast option B , as defined in section 11.2.1.2, and

z = the logit variable of the consumer choice model.

The logit variable z depends on the first cost and the average annual O&M cost of each lamp option. For a GSFL, the first cost is simply the sum of the purchase price (including sales tax) and the lamp installation cost. The average annual O&M cost for each lamp option is simply the electricity cost associated with operating the lamp on a given ballast for the sector-specific average annual operating hours. The average annual operating-hour values in each sector are computed as a weighted average of the annual hours of use in each of the building applications documented in section 11.3.6.6.

The market share projection for each lamp option can be converted to shares of the OSSDAP by summing over the market shares in prior years:

$$\phi_{l,B}(y) = \frac{\sum_{y'=y_{rule}}^{y'} MS_{l,B}(y') s_{GSFL,B}(y') P_{LBS}(y - y')}{\sum_{y'=y_{rule}}^{y'} s_{GSFL,B}(y') P_{LBS}(y - y')} \quad \text{Eq. 11.55}$$

Where:

$\phi_{l,B}(y)$ = the fraction of the OSSDAP of GSFLs installed on ballasts option B that is represented by lamp option l ,
 $s_{GSFL,B}(y)$ = the shipments of GSFLs installed on ballast option B in year y , as defined in Eq. 11.53 (number of units),
 $P_{LBS}(y - y')$ = the probability that a lamp and its ballast both survive for $y - y'$ years after the lamp's installation, as defined in Eq. 11.35, and
all other variables are as in Eq. 11.54.

11.3 MODEL CALIBRATION AND INPUTS

11.3.1 Estimation of Historical Shipments and Initial Market Shares

Because the lamp shipments modeled in any given year depend on sums of shipments of IRLs and GSFL ballasts in prior years, DOE needed historical data to initiate the shipments model. Although the GSFL shipments model does not require a historical time series of GSFL shipments (because it is derived from the ballast shipments), DOE used historical GSFL shipments data as a calibration tool by ensuring that the projected GSFL shipments were consistent with historical data.

To accurately compute the initial shipments and stock projections from historical data, it is necessary to have data spanning a sufficiently long time period such that products shipped at the beginning of the historical period have a negligible surviving fraction in today's stock. DOE estimates that, for IRLs, 10 years is a sufficiently long historical period to meet this criterion; for fluorescent ballasts a historical period of at least 30 years is required. Section 11.3.2 describes the sources of the historical shipments data; their disaggregation into different sectors, product classes, and technology options; and their use in initializing the shipments and stock model.

11.3.2 Sources of Historical Shipments Data

DOE obtained historical data on GSFL and IRL shipments from NEMA for the years 2006-2011. When combined with NEMA data provided for the 2009 lamps rulemaking, these data yield a continuous time series of shipments of GSFLs and IRLs by NEMA members over the period from 2000 to 2011. As mentioned previously, a historical period of at least ten years' duration is required for an accurate initialization of the IRL shipments model, so this data set is sufficient for that purpose. Where possible, the provided data were subdivided by NEMA into product categories that are very similar to the lamp types considered in this rulemaking analysis. The details of any further disaggregation or rearrangement of these data by DOE are given in section 9.3.1.2. To account for shipments to the U.S. market by non-NEMA members, DOE assumed that NEMA shipments accounted for a fixed fraction of the total U.S. shipments over the historical period, using the same fractions that were utilized in the 2009 lamps rulemaking.¹ These fractions are summarized in Table 11.3.1.

Table 11.3.1 Fraction of Lamp Shipments Assumed to be from NEMA Members

Product Type	Fraction of shipments from NEMA members
GSFL	90
IRL – Halogen	85
IRL – Traditional Incandescent	70

DOE also obtained data from NEMA on shipments of fluorescent ballasts for the years 2006-2011, divided into subcategories that are very similar to the lamp types considered in this rulemaking, with an additional subdivision into T12 and T8 ballasts where appropriate. (As discussed in section 11.1.1 DOE analyzed T8 and T12 lamps and ballasts separately in the shipments analysis and the NIA.) To estimate fluorescent ballast shipments from earlier years, DOE made use of data from the U.S. Census Bureau's Current Industrial Reports¹⁵ (CIR), which also were originally obtained from NEMA, spanning the years 1995 (the first year in which T8 shipments were reported separately from T12) to 2005 (the final year in which data were reported). To account for shipments to the U.S. market by non-NEMA members, DOE again assumed that NEMA shipments accounted for a fixed fraction of the total U.S. shipments over this period, using the same fractions that were utilized in the 2011 fluorescent ballasts rulemaking. These fractions are summarized in Table 11.3.2.

Table 11.3.2 Fraction of Ballast Shipments Assumed to be from NEMA Members

Ballast Type	Fraction of shipments from NEMA members
4-foot MBP T12 – Commercial	70
4-foot MBP T8 – Commercial	90
4-foot MBP T12 and T8 – Residential	50
8-foot SP slimline T12	70
8-foot SP slimline T8	90
8-foot RDC HO T12	60
8-foot RDC HO T8	90
4-foot Mini BPT5 SO	90
4-foot MiniBP T5 HO	90
4-foot MBP T8 – Commercial	90

As mentioned previously, a historical time series spanning 30 years is required for an accurate initialization of the fluorescent ballast shipments model. To obtain historical shipments of T12 ballasts for years prior to 1995, DOE made use of data from the *Lighting Market Sourcebook for the U.S.*¹⁶ and the Census Bureau's CIR,¹¹ which together span the period from 1977 to 2005 for 4-foot and 8-foot T12 ballasts. To estimate the shipments of T8 ballasts prior to 1995, DOE noted that T8s were a very small fraction of the market at that time, having only been introduced to the market in 1990. Therefore, DOE assumed a linear increase in historical T8 shipments from zero in 1989 to the CIR values in 1995. Because T5 lamps were introduced to the U.S. market after 1995, no modeling of their shipments in prior years was required.

As discussed in section 11.1.1, DOE included T12 lamps and ballasts in its model, even though they were largely eliminated by new standards with compliance dates in 2012, because T12 products remain a large fraction of the existing stock, making it necessary to model their retirement and replacement. As historical shipments data were only available through 2011, however, and as explicitly modeling T12 shipments in 2012 would require a significantly more complicated model, DOE simply extrapolated the disaggregated historical shipments data to 2012 for GSFLs and fluorescent ballasts, based on 2009-2011 trends. Modeling of GSFL and fluorescent ballast shipments was performed beginning in 2013. For IRLs no such extrapolation was necessary, and modeling began in 2012.

11.3.3 Subdivision of Historical Shipments by Sector, Lamp Type, and Technology

As mentioned previously, the historical shipments data from NEMA and the CIR are subdivided into categories that closely resemble the lamp types considered in this analysis. In a few cases, however, it was necessary to combine or further subdivide some of these categories to more accurately match the lamp types or technology options being modeled. It was also

necessary to subdivide the shipments in some cases into estimated shipments to the residential and the commercial and industrial sectors.

As mentioned in section 11.1.1, DOE models shipments of IRLs and 4-foot MBP GSFLs separately in the residential sector and the commercial (for IRL) or combined commercial and industrial (for GSFL) sectors. To subdivide the historical shipments data for these products appropriately, DOE estimated the residential fraction of each product's shipments from the estimates of lamp stocks in the 2010 LMC and from the mean lamp lifetimes in each sector:

$$f_{Res} = \frac{\frac{S_{Res}}{L_{Res}}}{\frac{S_{Res}}{L_{Res}} + \frac{S_{CI}}{L_{CI}}}$$

Eq. 11.56

Where:

f_{Res} = the fraction of lamp shipments in the residential sector,

S_{Res} = the stock of lamps in the residential sector, as reported in Table 4.1 of the LMC (number of units),

S_{CI} = the stock of lamps in the commercial (IRL) or commercial and industrial (GSFL) sectors, from the same table (number of units),

L_{Res} = the average lamp lifetime in the residential sector (yr), *i.e.*, the average failure age derived from the lamp failure distribution in Eq. 11.15 or Eq. 11.33 using the appropriate hours-of-use distribution and ballast lifetime for the residential sector, and

L_{CI} = the lamp lifetime in the commercial (IRL) or commercial and industrial (GSFL) sectors (yr), computed as above, except with the use of the appropriate hours-of-use distribution and ballast lifetimes for the commercial and industrial sectors.

The data on GSFL and fluorescent ballast shipments from NEMA and CIR were nearly all subdivided into categories corresponding directly to the analyzed lamp types, with additional subdivisions into T12 and T8 technologies, where appropriate. The exceptions were 8-foot recessed double contact (RDC) high output (HO) lamps and ballasts, for which no subdivision of the data into T12 and T8 technologies was available, and 4-foot MiniBP T5 standard output (SO) ballasts, for which no shipments were available from the CIR. To disaggregate the data for 8-foot RDC HO lamps and ballasts into T12 and T8 subcategories, DOE assumed that the fractions of T12 and T8 lamps within this lamp type were the same as the fractions for the 8-foot SP slimline lamp type. Similarly, to infer shipments of 4-foot MiniBP T5 SO ballasts prior to 2006, DOE assumed that the ratio of SO to HO T5 ballasts was fixed at its 2006 value in the period 2002-2005 and that there were zero shipments of 4-foot MiniBP T5 ballasts in any year before 2002.

As mentioned in section 11.2.2.3, DOE modeled the shipments independently for each of the three IRL technology options (the baseline lamp and two EL1 lamps), because their lifetimes were significantly different. It was, therefore, necessary to disaggregate the historical shipments data for IRLs into estimated shipments for each of the technology options. DOE is aware that many shipments prior to 2012 did not correspond to any of these three technology options, as compliance with the 2009 GSFL-IRL lamps rulemaking was challenging for some significant

types of IRL technology. Because these older technologies had lifetimes close to the Baseline lamp lifetime, however, it sufficed to categorize under Baseline all historical shipments outside the EL1 technology.

To disaggregate the historical IRL shipments, DOE used the consumer choice model to compute the expected market shares of the Baseline and two EL1 technology options in the commercial and residential sectors in 2012, denoting the EL1 fractions, $MS_{EL1,A}(2012)$ and $MS_{EL1,B}(2012)$, respectively, for the shorter and longer-lived EL1 lamp options. DOE assumed that the market share for the EL1 lamp option 1 (defined in Table 11.2.1) was constant over the period of the historical shipments. By researching historical manufacturer literature, DOE found that the technology options corresponding to EL1 lamp option 2 were only introduced to the U.S. market in or around 2007, so DOE assumed that the market share $MS_{EL1,B}(y)$, increased linearly in each year from zero in 2006 up to the 2012 value. The shipments of EL1 lamps in each year were then given by $s_{EL1,X}(y) = MS_{EL1,X}(y)s_{Tot}(y)$, where X takes the value A or B and $s_{Tot}(y)$ represents the total annual shipments in each sector. The remainder of the historical shipments were allocated to the Baseline lamp option for the purposes of initializing the shipments model.

11.3.4 Consumer Choice Module Calibration

This section describes the methods DOE used to determine the various model parameters that control the behavior of the consumer choice module used in this shipments analysis. These include the parameters of the logit model, the Bass adoption model, and the stock turnover model.

11.3.4.1 Logit Model Calibration

As introduced in section 11.2.1.2, DOE used a logit model, described by Eq. 11.1 and Eq. 11.2, as the main driver of the consumer choice model used to predict product market share. The logit has two parameters, β_{FC} and β_{OM} , which characterize consumer sensitivity to first cost and O&M cost, respectively. Because commercial and industrial customers are expected to respond to lighting costs similarly to one another but differently from residential customers, DOE calculated two sets of logit parameters, one for the commercial and industrial sectors and the other for the residential sector. The logit parameters for the residential sector were scaled from the results of the commercial and industrial sector analysis, as described below.

Following the procedure adopted by DOE's Solid State Lighting Program in its report on the *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*,³ (hereafter referred to as the SSL report) the shipments model calculates the logit parameters for the commercial and industrial sector using data on fluorescent lamps and ballasts, because GSFL usage is dominantly commercial and industrial. The results of the analysis were then used in the consumer choice model to reflect decision-making in that sector. The following describes how the logit parameters were obtained for the commercial and industrial sector.

Calculation of the logit parameters requires both market share data (shipments) and first cost and O&M cost data for products with different costs. DOE used 2007 aggregate data for

T12, T8 and T5 SO lamps and ballasts for this purpose. These products were chosen because they provide similar lighting service and were direct competitors in the market for new construction, retrofit, and renovation. Data from 2007 were used to avoid market distortion caused by the 2011 lamps rulemaking. The cost data included lamp and ballast systems costs and O&M costs to reflect the full cost of ownership. Specifically, DOE used cost data from the engineering analysis for the 2011 GSFL rulemaking on 2-lamp 4-foot MBP T12 and T8 systems and 2-lamp T5 SO systems with similar system lumen output.

Table 11.3.3 lists the cost and market share input data used in the calibration. First costs include the price of the lamps and ballast, installation, and sales tax^h. As a proxy for the annual O&M cost, DOE used the electricity cost for the first year of system operation, which is calculated from system wattage, annual run hours, and the cost of electricity in 2007. All costs were normalized by dividing by the lumen output of the system. Market shares were computed from the shipments data that DOE received from NEMA in 2007, correcting for the fraction of GSFL shipments originating from NEMA members. Additionally, the shipments data were corrected to account for the fact that T5s are a relatively new technology and thus had a limited market presence in 2007. DOE corrected the 2007 market shares using the Bass diffusion curve (detailed in section 11.3.4.2) to reflect the market shares that would be expected if T5s had achieved full market penetration. This yields a significant upward correction to the market share of T5s.

Table 11.3.3 Input Data for Logit Parameter Calibration

Lighting System	First Cost (\$/thousand lumens)	O&M Cost (\$/thousand lumens)	Corrected 2007 Market Share***
T12	11.25	4.30	5%
T8 MBP	11.07	3.71	59%
T5 SO	13.24	2.86	37%

* May not add due to rounding

** Market shares were corrected to account for the fact that T5s are a new technology using the Bass diffusion curve detailed in section 11.3.4.2.

Using the input data from Table 11.3.3 in Eq. 11.1 and Eq. 11.2 results in the system of equations below, were solved for β_{FC} and β_{OM} .ⁱ

^h DOE looked into the effects of utility rebates on first costs seen by consumers by studying a comprehensive dataset of nationwide rebate programs compiled by the Consortium for Energy Efficiency for 2011. These data do not indicate any substantive difference in rebate amounts between high efficiency T8 lamps or lamp and ballast systems and T5 lamps or lamp and ballast systems. Therefore, no adjustments to first costs were made to account for rebates.

ⁱ In practice this system of equations is difficult to solve analytically. To solve numerically, DOE used Microsoft Excel's Solver tool to minimize the sum of squared residuals between the probabilities predicted by the logit model using the input prices and the market shares listed in Table 11.3.3.

$$0.05 = \frac{e^{11.25\beta_{fc} + 4.30\beta_{om}}}{e^{11.25\beta_{fc} + 4.30\beta_{om}} + e^{11.07\beta_{fc} + 3.71\beta_{om}} + e^{13.24\beta_{fc} + 2.86\beta_{om}}}$$

$$0.59 = \frac{e^{11.07\beta_{fc} + 3.71\beta_{om}}}{e^{11.25\beta_{fc} + 4.30\beta_{om}} + e^{11.07\beta_{fc} + 3.71\beta_{om}} + e^{13.24\beta_{fc} + 2.86\beta_{om}}}$$

$$0.37 = \frac{e^{13.24\beta_{fc} + 2.86\beta_{om}}}{e^{11.25\beta_{fc} + 4.30\beta_{om}} + e^{11.07\beta_{fc} + 3.71\beta_{om}} + e^{13.24\beta_{fc} + 2.86\beta_{om}}}$$

The results of the calibration are listed in Table 11.3.4.

Table 11.3.4 Logit Parameter Results from Calibration

Sector	β_{FC}	β_{OM}
Commercial/Industrial	-1.72	-3.80
Residential	-0.95	-1.90

For the residential sector, the SSL report used data for medium screw-base lamps to calibrate the logit parameters. Given that reliable residential sector price data were unavailable for this analysis, DOE scaled the commercial and industrial logit parameters to obtain the residential logit parameters shown in Table 11.3.4, consistent with the results of the SSL report.^j

11.3.4.2 Bass Adoption Model

As discussed in section 11.2.1.2 DOE used a diffusion curve developed by PNNL¹⁷ for its shipments model. The adoption curve parameters used in Eq. 11.3 are shown in Table 11.3.5 and the curve is plotted in Figure 11.3.1.

Table 11.3.5 Bass Adoption Model Parameters

CE	0.005
CI	0.25

^j The analysis performed for the SSL report made use of proprietary data not available for the analysis presented in this TSD.

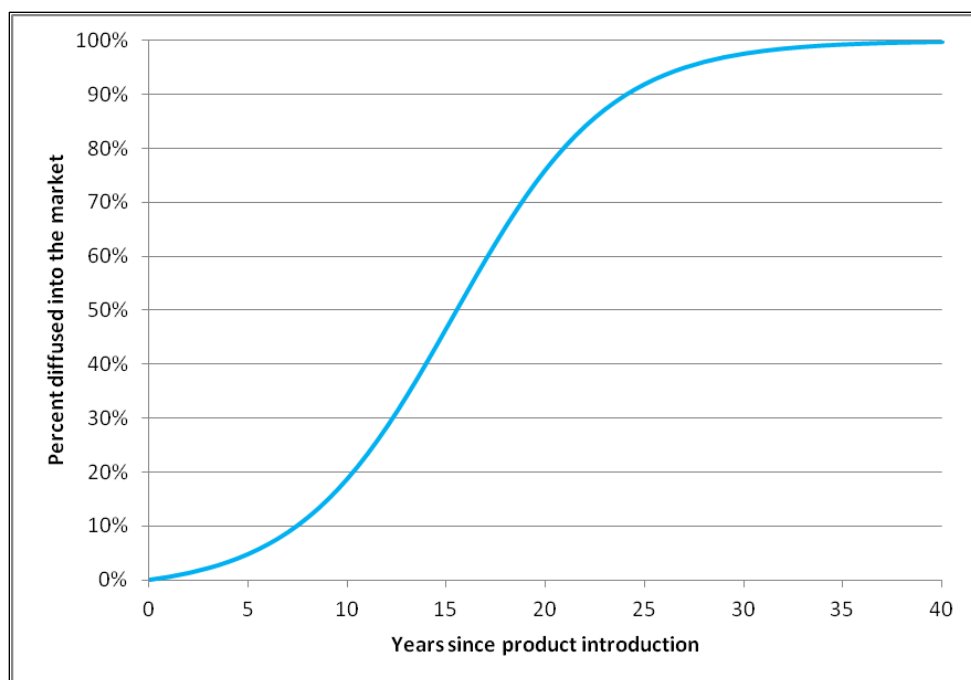


Figure 11.3.1 Generic lighting Bass diffusion curve

11.3.4.3 Stock Turnover Calibration

To calibrate the stock turnover portion of the consumer choice module for GSFL^k, DOE varied the following model parameters:

- the acceptance factors for lamp types and lamp-ballast pairings,
- the assumed average number of lamps per ballast for the various ballast technologies, and
- the assumed lifetimes of certain ballasts.

DOE varied these parameters to accurately capture the present-day observed market shares of lamp types and lamp options, as compared to what would be predicted using the price factors in the logit model alone.

As discussed in section 11.2.1.2, DOE uses acceptance factors to limit the potential market shares of options whose selection is heavily impacted by non-economic factors relative to other options. Acceptance factors limit the total market share that can be assigned to a product and are normally set to 1 for products with a wide acceptance among consumers. In the GSFL turnover model, DOE applied acceptance factors to entire lamp types and to individual GSFL lamp-ballast pairings.

^k No particular calibrations were required for the IRL stock turnover model.

For the lamp types, DOE noted that consumers show a preference for 4-foot lamps over 8-foot lamps, as evidenced by shipments data. Therefore, during calibration, acceptance factors were reduced for 8-foot slimline and 8-foot RDC HO lamp types until the shipments predicted by the consumer choice module in the first year of the analysis period were consistent with the 2011 shipment data provided by NEMA for these products. After calibration the acceptance factors were assumed to apply over the entire analysis period. The acceptance factors for GSFL lamp types are presented in Table 11.3.8.

For the lamp-ballast options, DOE calibrated the acceptance factors using the current market share of certain reduced-wattage 4-foot MBP lamps. The full details of this calibration are presented in section 11.3.6.3, and the acceptance factors for the lamp-ballast pairings are listed in Table 11.3.12 - Table 11.3.16. After calibration the acceptance factors were assumed to apply over the entire analysis period.

DOE calibrated ballast lifetimes using lifetime reduction factors to reduce certain ballasts' average lifetimes to account for consumers' potentially retiring ballasts for reasons other than failure, such as new standards eliminating some lamp options (*e.g.*, T12s) or a preference of 4-foot lamps over 8-foot lamps. In the final calibration, ballast lifetime reduction factors were reduced for T12 ballasts and ballast options that accept 8-foot lamps until shipments in the analysis period were consistent with historical ballast shipment trends. Again, after calibration, these parameters were not changed. The lifetime reduction factors used in this rulemaking analysis are listed in Table 11.3.9.

Once the ballast turnover model was fully calibrated, DOE varied its assumptions regarding the average number of lamps per ballast for each ballast technology until the projected lamp shipments in 2013 were consistent with historical trends. The average number of lamps per ballast that DOE assumed in this rulemaking analysis are presented in Table 11.3.9.

11.3.5 Price Learning

As indicated in section 11.2.1.3, DOE uses a price learning model to project future prices in its shipments analysis. Accordingly, the initial lamp prices determined in the pricing analysis (chapter 7 of this TSD) are adjusted for the observed learning rate at later times in the analysis period. DOE developed price learning rates for the two categories of lamps and for GSFL ballasts based on historical shipments data from the U.S. Census CIR¹⁵. DOE extracted the historical product data indicated in Table 11.3.6 from the CIR to calculate price learning rates for GSFLs, IRLs, and ballasts.

Table 11.3.6 Data Extracted from Current Industrial Reports (CIRs) for Price Learning Analyses

Dates	CIR product category	Product addressed in rulemaking
1958 to 1994	fluorescent, hot cathode (GSFL)	GSFL
1960 to 1994	PAR	IRL
1986 to 2005	electronic ballasts	ballasts

The CIRs report annual data on shipments (units shipped) and the total nominal dollar value of those shipments. DOE interpolated reported shipments to estimate missing year values and extrapolated to estimate shipments back to the first year of shipments. Those data were then used to calculate the annual cumulative production (Eq. 11.5) used in the price learning analysis. The dollar values reported in the CIRs represent the net selling value of units shipped free-on-board (FOB) from the factory¹. These were converted to per-unit sales values and adjusted for inflation using the U.S. Office of Budget and Management Gross Domestic Product chained price index¹⁸. The data on price and cumulative shipments were then fitted to the learning curve (Eq. 11.4) to calculate the learning rates used in the shipments model. The results of these fits are shown in Figure 11.3.3, Figure 11.3.4, and Figure 11.3.4 for IRL, GSFL, and ballasts, respectively. The equations in the figures indicate the fits to Eq. 11.4 for each of the product groups. The rate parameters (exponents) were then used in Eq. 11.6 to determine the product group specific price learning factors, which in turn were used by the model, in Eq. 11.7, to calculate the prices in any given year.

¹ Free-on-board values reflect discounts and allowances, are exclusive of excise taxes, but include freight charges. This approximates the cost of production to the manufacturer plus a single mark-up to the first customer, most likely a distributor. Ideally, consumer prices would have been used for this analysis, rather than the manufacturer selling prices given in the CIR, but the CIR data were considered the best option for two reasons. (1) Given the assumption of constant markups, the learning rates deducted from the manufacturer selling prices will be the same as for the retailer selling prices. (2) The multi-decade CIR data constituted the most comprehensive and consistent data source available that covered the longest time period.

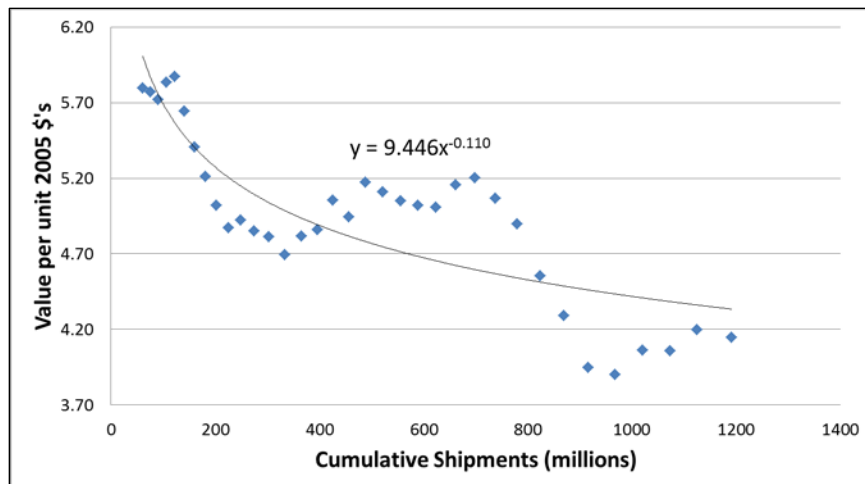


Figure 11.3.2 IRL Learning Curve

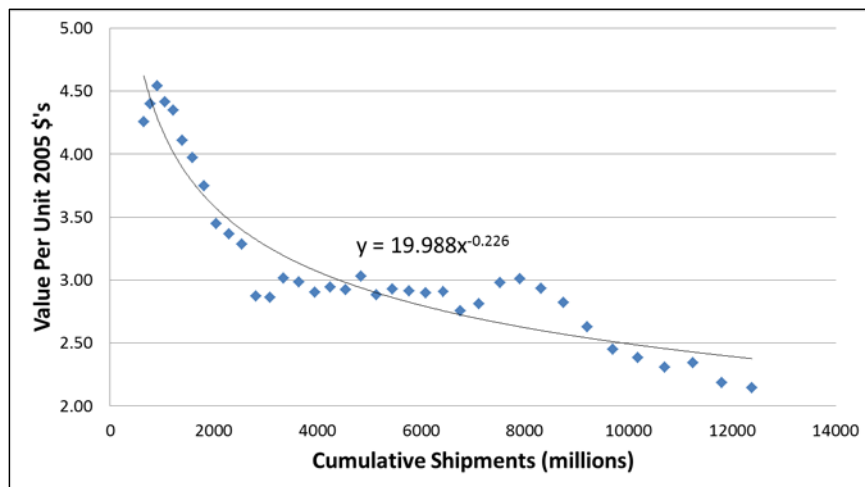


Figure 11.3.3 GSFL Learning Curve

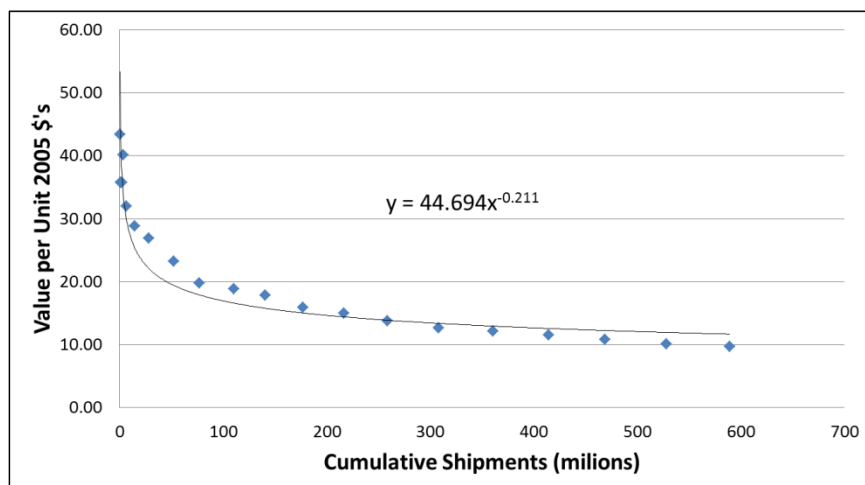


Figure 11.3.4 Ballast Learning Curve

11.3.6 Lamp and Ballast System Assumptions

As discussed in chapters 5 and 6 of this TSD, computing the power usage associated with a particular GSFL requires assumptions about the ballast to which it is coupled. In those chapters, DOE analyzed GSFLs coupled to particular representative ballasts to determine representative energy consumption values. In the NIA, however, since lamps and ballasts are sold separately, it is necessary to consider a broader array of lamp-ballast pairings that consumers might choose to fulfill their lighting applications. In addition, the shipments model considers the possibility that consumers will switch between different product classes in response to economic signals. This section details the properties of the lamps, ballasts, lamp-ballast pairings, and lamp-type substitutions that DOE considered in the shipments analysis and NIA. This section also presents the properties of the IRL options that DOE considered in the shipments analysis and NIA, which are identical to the options considered in earlier chapters.

11.3.6.1 GSFL Lamp Type Substitution Assumptions

Table 11.3.7 indicates which lamp types the shipments model considers to be allowable substitutes for lamp types whose existing lamp-ballast systems that are replaced during retrofits or renovations. An X in an intersecting column and row indicate that a system from the lamp type in the column header may be replaced by a system from the lamp type in the row header. In developing this matrix, DOE considered lamp types to be potential substitutes if they are used for similar applications. DOE also assumed that in some cases consumers do not switch from newer back to older technologies (*e.g.*, there is no switching from T5 HO systems to 8-ft RDC HO systems). Note that, as discussed in section 11.1.1 no T12 systems were allowed to substitute for any existing systems, even for existing T12 systems, because DOE assumes that they do not comply with the 2011 fluorescent lamp ballast rulemaking¹¹. For the purposes of lamp-ballast system changes, all new systems were assumed to consist only of non-T12 options.

Table 11.3.7 Allowed Lamp Type Substitution for Retrofits and Renovations

		Lamp type of retiring system					
		4-foot MBP (Commercial Sector)	4-foot MBP (Residential Sector)	8-foot SP Slimline	8-foot RDC HO	T5 SO	T5 HO
Lamp type of replacement system	4-foot MBP (Commercial Sector)	X		X		X	
	4-foot MBP (Residential Sector)		X				
	8-foot SP Slimline			X			
	8-foot RDC HO				X		
	T5 SO	X		X		X	
	T5 HO				X		X

As discussed in section 11.3.4.3 the model uses acceptance factors for lamp types, listed in Table 11.3.8 below. DOE calibrated these factors by ensuring that the projected shipments of ballasts in the base case were consistent with historical data.

Table 11.3.8 Lamp Type Acceptance Factor

Lamp Type	Acceptance Factor
4-ft MBP	1
8-foot SP Slimline	1
8-ft RDC HO	0.3
4-foot T5 SO	1
4-foot T5 HO	1

11.3.6.2 Fluorescent Ballast Assumptions

This section documents the model inputs for fluorescent ballasts in the following tables:

- Table 11.3.9. Properties of the ballast technologies within each lamp type, and
- Table 11.3.10. Properties of the ballast factor options within each ballast technology.

Values listed in Table 11.3.9 are directly from the engineering analysis (chapter 5 of this TSD) or calculated from engineering analysis data except for the average lamps per ballast and lifetime reduction factor. These numbers are from model calibration as discussed in 11.3.4.

Table 11.3.9 Properties of Representative Fluorescent Ballast Technologies

Ballast technology	4-foot MBP T12 (Commercial and Industrial)	4-foot MBP T8 Instant Start (Commercial and Industrial)	4-foot MBP T8 Program start (Commercial and Industrial)	4-foot MBP T12 (Residential)	4-foot MBP T8 (Residential)	8-foot Single Pin SP slimline T12	8-foot Single Pin SP slimline T8	8-foot RDC High Output T12	8-foot RDC High Output T8	Two Lamp PS T5 SO	Two Lamp PS T5 HO
Group Relamping Fraction[†]	0.25	0.25	0.25	0.00	0.00	0.37	0.37	0.31	0.31	0.25	0.25
Average Lamps Per Ballast	2.6	2.88	2.52	2	2.4	2	2	2	2	2.4	2.4
Rated Life Hours	18938	24000	40000	18938	24000	11108	24000	11070	18000	30000	24000
Lamp Life Hours*	18228	23100	38500	18938	24000	10492	22668	10555	17163	28875	24063
Lamp Life Years^{††}	5.3	6.6	10.6	18.1	18.5	3.3	6.5	3.3	5.0	8.1	6.8
Representative System Mean Lumens**	5262	6809	6005	4002	5638	10276	9396	13195	12312	6840	11280
Ballast Price	N/A	\$19.17	\$19.74	N/A	\$9.25	N/A	\$20.21	N/A	\$16.11	\$27.75	\$29.05
Ballast Installation Cost	N/A	\$31.65	\$26.68	N/A	\$33.55	N/A	\$56.77	N/A	\$60.76	\$26.85	\$26.85
Lamp Installation Cost	N/A	\$6.82	\$6.77	N/A	\$0.00	N/A	\$4.74	N/A	\$6.34	\$6.70	\$6.70
Fixture Disconnect Cost	N/A	\$2.80	\$2.80	N/A	\$2.80	N/A	\$2.80	N/A	\$2.80	\$2.80	\$2.80
Lamp disposal cost	N/A	\$0.24	\$0.24	N/A	\$0.00	N/A	\$0.48	N/A	\$0.48	\$0.24	\$0.24
Lifetime Avg. Lamps	5.94	5.3	2.9	2	2.4	7.4	3.7	7.4	4.8	3.6	4.3

Ballast technology	4-foot MBP T12 (Commercial and Industrial)	4-foot MBP T8 Instant Start (Commercial and Industrial)	4-foot MBP T8 Program start (Commercial and Industrial)	4-foot MBP T12 (Residential)	4-foot MBP T8 (Residential)	8-foot Single Pin SP slimline T12	8-foot Single Pin SP slimline T8	8-foot RDC High Output T12	8-foot RDC High Output T8	Two Lamp PS T5 SO	Two Lamp PS T5 HO
Bass Introduction Year [†]	1950	1989	1989	1950	1989	1950	1989	1950	1989	2001	2001
Lifetime Reduction Factor	0.7	1	1	0.5	1	1	1	1	1	1	1
Industrial Fraction ^{**}	0.06	0.08	0.08	0.00	0.00	0.09	0.11	0.09	0.11	0.08	0.08

Source: Engineering analysis (chapter 5 of this TSD) and LCC (chapter 8 of this TSD) unless otherwise noted (with 2 and 4 lamp ballasts aggregated into weighted averages based on number of lamps per ballast). Prices are given in 2011\$ for the beginning of the analysis period (2012).

* Includes the effect of group relamping on average lamp lifetime.

** System lumens were calculated assuming lamps are installed on a reference ballast coupled to a reference lamp; see section 11.3.6.4

** These values are computed by the consumer choice model for lamps, based on inputs from the engineering analysis. They are then used as inputs to the consumer choice model for ballasts in 2013. New inputs are computed for subsequent years from the output of the previous year, as described in section 11.2.2.

[†] Source: 2011 fluorescent lamp ballast rulemaking TSD.¹¹

^{††} Computed from Eq. 11.29

[‡] Introduction year for T12s is arbitrary since T12 are not a choice in the consumer choice module. T8 introduction year from Elliot *et al.* 2004.¹⁷ T5 introduction year from 2011 fluorescent lamp ballast rulemaking TSD.¹¹

^{‡‡} Computed from LMC stock fractions of commercial and industrial stock.

Table 11.3.10 Properties of the Ballast Options by Lamp Type and Ballast Technology

Lamp Type	Ballast Technology	Ballast Factor Option	Ballast Option ID	Ballast Factor	Ballast Luminous Efficiency
4-foot MBP Commercial Sector	Instant start	Normal	B1.IN	0.88	93.2
		Low	B1.IL	0.78	92.4
	Program start	Normal	B1.PN	0.88	91.7
		Low	B1.PL	0.76	90.4
	Dimming	N/A	B1.D	Varies*	81.3
4-foot MBP Residential Sector	Instant start	Normal	B1R.IN	0.87	89.3
		Low	B1R.IL	0.83	89.7
8-foot Slimline	Instant start	Normal	B2.IN	0.87	94.3
		Low	B2.IL	0.77	93.5
8-foot HO	Instant start	Normal	B3.I	0.81	91.7
T5 SO	Program start	Normal	B4.PN	1.0	92.1
		Low	B4.PL	0.85	89.2
	Dimming	N/A	B4.D	Varies*	92.1
T5 HO	Program start	Normal	B5.PN	1.0	92.4
	Dimming	N/A	B5.D	Varies*	92.4

*Ballast factors for dimming ballasts coupled to the various available lamp options are as utilized in the LCC analysis (chapter 8 of this TSD).

11.3.6.3 General Service Fluorescent Lamp and Lamp-ballast Pairing Assumptions.

Table 11.3.11 documents the properties of the GSFL options that DOE utilized in the shipments analysis and NIA. For those two analyses, DOE considered coupling these lamp options to the ballast options summarized in section 11.3.6.2. Not all possible pairings were allowed in the analysis. The criteria that DOE used to determine the allowed lamp-ballast pairings were the following:

- paired lamps and ballasts must be of the same lamp type, where the lamp types for the different ballast options are given in Table 11.3.10,
- the lamp option must be compatible with the ballast technology (*e.g.*, lamps on dimming ballasts must be capable of dimming), and
- the lamp-ballast pairing must provide lighting levels that are acceptable to the consumer.

Table 11.3.11 Properties of Representative GSFL Options: Baseline and All ELs

Lamp Type	EL	Lamp Option ID	Lamp Diameter	Nominal Wattage	ANSI Rated Wattage	Reference Arc Power	Efficacy (rated [lm/W])	Initial Lumens	Mean Lumens	Lamp Price
4-foot MBP	Baseline	L1.0.1	T8	32	32.5	29.0	89.2	2900	2725	\$4.99
	EL1	L1.1.1	T8	32	32.5	29.0	90.0	2925	2770	\$5.51
	EL2	L1.2.1	T8	32	32.5	29.0	95.4	3100	2945	\$9.54
		L1.2.2	T8	28	28.4	26.0	96.0	2725	2590	\$8.23
		L1.2.3	T8	25	26.6	24.2	93.0	2475	2350	\$11.00
8-foot SP Slimline	Baseline	L2.0.1	T8	59	60.1	57.0	96.5	5800	5220	\$10.48
	EL1	L2.1.1	T8	59	60.1	57.0	98.2	5900	5490	\$11.74
	EL2	L2.2.1	T8	59	60.1	57.0	99.0	5950	5650	\$14.18
		L2.2.2	T8	54	54.0	54.0	105.6	5700	5415	\$18.46
		L2.2.3	T8	50	50.0	50.0	108.0	5400	5075	\$21.97
8-foot HO	Baseline	L3.0.1	T8	86	84.0	84.0	92.0	7728	7342	\$8.63
	EL1	L3.1.1	T8	86	84.0	84.0	95.2	8000	7600	\$13.19
	EL2	L3.2.1	T8	86	84.0	84.0	97.6	8200	7800	\$16.61
T5 SO	Baseline	L4.0.1	T5	28	27.8	27.8	94.6	2630	2446	\$4.10
	EL1	L4.1.1	T5	28	27.8	27.8	104.3	2900	2697	\$5.94
	EL2	L4.2.1	T5	28	27.8	27.8	109.7	3050	2898	\$7.06
		L4.2.2	T5	26	26.0	26.0	111.5	2900	2755	\$8.56
		L4.2.3	T5	25	25.0	25.0	116.0	2900	2750	\$9.87
T5 HO	Baseline	L5.0.1	T5	54	53.8	53.8	83.6	4498	4273	\$5.66
	EL1	L5.1.1	T5	54	53.8	53.8	92.9	5000	4750	\$9.48
		L5.1.2	T5	49	49.0	49.0	102.0	5000	4600	\$12.30
		L5.1.3	T5	47	47.0	47.0	102.1	4800	4410	\$13.69

Source: Engineering analysis (chapter 5 of this TSD).

Prices are given in 2011\$ for the beginning of the analysis period (2012).

DOE received numerous comments from industry suggesting that reduced-wattage lamps are either incompatible with dimming ballasts or provide unreliable performance when coupled to such ballasts. As discussed in chapter 5 of this TSD, DOE did find dimming ballasts on the market that are advertised as being compatible with reduced-wattage lamps of the 4-foot MBP

lamp type. Therefore, for the 4-foot MBP lamp type, DOE allowed reduced-wattage lamps to be coupled to dimming ballasts. However, because the performance of such pairings may be unreliable in many applications, DOE assumed that consumer acceptance of this pairing is limited to 10% of the market for dimming ballast systems. For all other lamp types with dimming ballasts, DOE assumed that reduced-wattage lamps cannot be paired with dimming ballasts.

In considering the light-output criterion, DOE assumed that consumers are generally insensitive to changes in light levels of less than 10%, as discussed in chapter 5 of this TSD. Therefore, the shipments analysis and NIA considered all lamp-ballast pairings that have lumen packages within 10% greater^m or less than the lumen packages of the baseline system considered for the same ballast technology in the LCC analysis (chapter 8 of this TSD). In addition, as discussed in chapter 5 of this TSD, DOE believes that some consumers may accept lumen reductions greater than 10% in order to save energy. Indeed, one of the reduced-wattage lamp options for the 4-foot MBP lamp type, which is currently available on the market, has a lumen output that is 14% lower than the relevant baseline lamp's lumen output. DOE therefore assumed that some fraction of consumers are willing to consider lamp-ballast pairings that have light output up to 14% below the baseline lumen package.

As discussed in section 11.3.4.3, DOE assumed in the shipments analysis that not all lamp-ballast pairings have complete acceptance among consumers. In particular, DOE believes that reduced-wattage lamps have performance problems in certain applications (*e.g.*, cold temperatures), limiting their maximum possible market share. Also, as just mentioned, DOE assumed that only a fraction of consumers would consider saving energy by reducing light output by between 10 and 14%. DOE therefore assigned acceptance factors to certain lamp-ballast pairings in the shipments analysis.

DOE determined appropriate acceptance factors for the lamp-ballast pairings by varying the acceptance factors for 28-watt and 25-watt reduced wattage 4-foot MBP lamps until the model reproduced the current market shares for those two lamp optionsⁿ. DOE then assumed that the resulting acceptance factors for the 28-watt and 25-watt 4-foot MBP lamps corresponded, respectively, to globally applicable acceptance factors for reduced-wattage and reduced-lumen lamp-ballast pairings.

The acceptance factors that DOE assumed for all possible lamp-ballast pairings are summarized in Table 11.3.12 - Table 11.3.16. Pairings that are disallowed in the analysis are denoted by an acceptance factor of zero.

^m In the case of high-output systems (both 8-foot RDC and T5 HO), DOE assumed that a greater lumen package was a desirable attribute, so lamp-ballast pairings more than 10% brighter than the baseline were also included among the permissible options.

ⁿ These market shares were estimated in manufacturer input to DOE to be 2-10% for 25W lamps and 3-15% for 28W lamps.

Table 11.3.12 Lamp Acceptance Factors by Ballast Option, 4-foot MBP

Lamp Option	B1.IN*	B1.IL	B1.PN	B1.PL	B1.D	B1R.IN	B1R.IL
L1.0.1**	1	0.5	1	0.5	1	1	0.5
L1.1.1	1	1	1	0.5	1	1	1
L1.2.1	1	1	1	1	1	1	1
L1.2.2	0.6	0.3	0.6	0	0.1	0.6	0.5
L1.2.3	0.5	0	0.5	0	0.1	0.5	0

*Ballast option codes are as defined in Table 11.3.10.

**Lamp option codes are as defined in Table 11.3.11

Table 11.3.13 Lamp Acceptance Factors by Ballast Option, 8-foot Slimline

Lamp Option	B2.IN*	B2.IL
L2.0.1**	1	0.5
L2.1.1	1	1
L2.2.1	1	1
L2.2.2	1	1
L2.2.3	1	0.5

*Ballast option codes are as defined in Table 11.3.10.

**Lamp option codes are as defined in Table 11.3.11

Table 11.3.14 Lamp Acceptance Factors by Ballast Option, 8-foot HO

Lamp Option	B3.I*
L3.0.1**	1
L3.1.1	1
L3.2.1	1

*Ballast option codes are as defined in Table 11.3.10.

**Lamp option codes are as defined in Table 11.3.11

Table 11.3.15 Lamp Acceptance Factors by Ballast Option, T5 SO

Lamp Option	B4.PN*	B4.PL	B4.D
L4.0.1**	1	0	1
L4.1.1	1	1	1
L4.2.1	0	1	1
L4.2.2	0	0.6	0
L4.2.3	0	0.6	0

*Ballast option codes are as defined in Table 11.3.10.

**Lamp option codes are as defined in Table 11.3.11

Table 11.3.16 Lamp Acceptance Factors by Ballast Option, T5 HO

Lamp Option	B5.PN*	B5.D
L5.0.1**	1	1
L5.1.1	1	1
L5.1.2	0.6	0
L5.1.3	0.6	0

*Ballast option codes are as defined in Table 11.3.10.

**Lamp option codes are as defined in Table 11.3.11

11.3.6.4 Reference Lamp and System Properties for Each Lamp Type

As mentioned earlier in this chapter, when converting between lumen demand and demand for lamps within the different lamp types, and when considering substitutions between lamp types or between ballast options associated with a given lamp type, DOE used a reference set of lamp properties to represent each lamp type. DOE chose these reference values to approximate the properties of the most common, least efficacious systems considered in the engineering analysis that are available on the market today, while also being comparable across lamp types that DOE considers to be direct substitutes for one another. For IRLs, the reference lamp properties are simply the properties of the baseline lamp. The reference GSFL properties DOE used in this analysis when considering each lamp type as a whole are summarized in Table 11.3.17.

Table 11.3.17 Reference Lamp Properties for each Lamp Type

Lamp Type	Reference Lumens	Reference Arc Power
4-ft MBP	2700	29
8-foot SP Slimline	5400	57
8-ft RDC HO	7600	84
4-foot T5 SO	2700	27.8
4-foot T5 HO	4700	53.8

In addition to the reference lamp properties summarized in Table 11.3.17, it was sometimes necessary to consider the price of a reference lamp (*e.g.*, in the context of a consumer's choosing a lamp type or ballast option). In these cases, DOE chose the price of the least efficacious full-wattage lamp option with an acceptance factor of 1.0 that would be available under a standard at the TSL being considered. These reference lamp properties were combined with the ballast properties summarized in Section 11.3.6.2, using Eq. 11.24 and Eq. 11.46 to produce reference lamp-ballast system properties for use when converting from lighting capacity demand to demand for new ballast shipments, or when considering a consumer choice between different ballast options associated with a given lamp type.

When considering a consumer choice between two lamp types, DOE computed reference system properties using the reference lamp properties and a single reference ballast for the lamp type, depending on whether the consumer subgroup being considered was implementing dimming controls, switching-only controls, or no controls. For consumers with dimming controls, DOE selected the dimmable ballast associated with each lamp type as the reference ballast. For consumers with switching-only controls or no controls, DOE selected a non-dimmable ballast as the reference ballast. In the case of the 4-foot MBP lamp type, DOE selected an instant-start reference ballast for consumers without controls and a programmed-start reference ballast for consumers with switching only controls (for other lamp types, only one non-dimming ballast technology is available, so it was used in both cases).

In each non-dimming case, when more than one ballast factor option was available the reference ballast selected was the higher ballast-factor option, since this is the same as the ballast used in the baseline system for the relevant ballast technology in the LCC analysis (chapter 8). The only exception to this was in cases where a standard would eliminate all lamp options that provide acceptable light output on the high ballast-factor ballast, as occurs at EL2 for T5 SO lamps coupled to non-dimming ballasts. In that case, the lower ballast-factor option of the same type was selected for reference.

11.3.6.5 Incandescent Reflector Lamp Characteristics

Table 11.3.18 shows the IRL lamp characteristics assumed by the shipments model.

Table 11.3.18 IRLs: Representative Properties for Baseline and EL 1 Lamps

	Residential Baseline	Residential EL1 Lamp 1	Residential EL1 Lamp 2	Commercial Baseline	Commercial EL1 Lamp 1	Commercial EL1 Lamp 2
Rated Wattage*	60	56	55	60	56	55
Dimmer Fraction	0.29	0.29	0.29	0.05	0.05	0.05
Dimming Energy Reduction	0.2	0.2	0.2	0.2	0.2	0.2
Dimming Lifetime Correction Factor	3.94	3.94	3.94	3.94	3.94	3.94
Wattage*	56.52	52.752	51.81	59.4	55.44	54.45
Efficacy (lm/w)	17.8	18.5	18.5	17.8	18.5	18.5
Rated Lamp Life Hours	1500	2500	4200	1500	2500	4200
Lamp Life Hours*	2779	4632	7781	1721	2868	4817
Lamp Life Years**	3.6	6.1	10.2	0.38	0.63	1.06
Initial Lumens	1070	1036	1018	1070	1036	1018
Lamp Installation Cost	0	0	0	1.13	1.13	1.13
Lamp Price	\$9.46	\$12.02	\$13.91	\$9.46	\$12.02	\$13.91
Lamp First Cost	\$9.46	\$12.02	\$13.91	\$10.59	\$13.15	\$15.04
Annual O&M***	\$6.64	\$5.44	\$4.56	\$44.32	\$33.04	\$24.19
Sector	Res	Res	Res	Com	Com	Com
Rated Lamp Life Hours - Short	1046	2500	4200	1046	2500	4200
Lamp Life Hours - Short	1937.8	4631.5	7780.9	1199.8	2867.5	4817.4
Lamp Life Years - Short	2.5	6.1	10.2	0.3	0.6	1.1
Initial Lumens - Short	1124	1036	1018	1124	1036	1018
Annual O&M - Short	\$7.77	\$5.44	\$4.56	\$56.42	\$33.04	\$24.19
Bass Introduction Year†	1980	1991	2007	1980	1991	2007
2011 Market Share††	0.60	0.38	0.01	0.70	0.29	0.01
Acceptance Factor	1	1	1	1	1	1
Weighted Average Lamp Price (2012\$)	\$8.83	\$11.22	\$12.98	\$8.83	\$11.22	\$12.98

Source: Engineering analysis unless otherwise noted. Prices are given in 2011\$ for the beginning of the analysis period (2012).

* Wattage and lamp life hours are adjusted to account for lamps on dimmers (see section 11.2.2.2).

** Average, dimmer-corrected lamp life in years calculated from Eq. 11.15.

*** Computed using Eq. 11.38

† Baseline 1 introduction year set to ensure 100% market penetration by 2011, as this is a mature technology. EL 1 lamp 1 and EL 1 lamp 2 from gelighting.com.¹⁹

†† Extrapolated from the 2012 market shares produced by the consumer choice module, as described in section 11.3.3.

11.3.6.6 Lamp Usage Assumptions

Table 11.3.19, Table 11.3.20, and Table 11.3.21 document, for the two categories of lamps in each of the three sectors, the model assumptions for lamp usage (hours per year), starts per day, and the probability that the space in which a lamp is installed is of a given type.

Table 11.3.19 Commercial Sector Annual Hours of Lamp Use and Starts per Day

Building Use Type	GSFL Probability*	GSFL Hrs*	IRL Probability*	IRL Hrs*	Starts Per Day**
Education	10.0%	4028	8.0%	4526	5
Food Service	2.5%	4064	1.3%	4380	2
Food Store	3.3%	4137	1.2%	4490	2
Health Care - Inpatient	2.9%	4028	1.2%	4453	5
Health Care - Outpatient	2.9%	4028	1.1%	4490	2
Lodging	3.4%	4028	4.4%	4453	5
Offices (Non-medical)	23.3%	4028	9.6%	4490	4
Public Assembly	3.9%	4064	2.2%	4417	4
Public Order and Safety	1.3%	4028	0.5%	4526	2
Religious Worship	6.0%	4028	2.4%	4417	2
Retail - Mall & Non-Mall	21.2%	4174	54.3%	4563	2
Services	7.2%	4028	2.7%	4526	2
Warehouse and Storage	10.4%	4028	8.2%	4526	4
Other	1.7%	4028	3.0%	4563	4
Total	100.0%		100.0%		
Average		4065		4532	3.28

* Source: Energy use analysis (chapter 6 of this TSD).

** Source: Expert opinion.

Table 11.3.20 Industrial Sector Annual Hours of Lamp Use and Starts per Day

Building Use Type	GSFL Probability*	GSFL Hrs*	Starts Per Day**
Apparel	1%	4582	2
Beverage and Tobacco Products	2%	4582	2
Chemicals	7%	4582	2
Computer and Electronic Products	8%	4582	2
Electrical Eq. Appliances & Components	4%	4619	2
Fabricated Metal Products	8%	4619	2
Food	4%	4545	2
Furniture and Related Products	4%	4545	2
Leather and Allied Products	0%	4582	2
Machinery	5%	4545	2
Nonmetallic Mineral Products	2%	4582	2
Paper	1%	4545	2
Petroleum and Coal Products	0%	4545	2
Plastics and Rubber Products	7%	4619	2
Primary Metals	6%	4619	2
Printing and Related Support	6%	4619	2
Textile Mills	2%	4582	2
Textile Product Mills	0%	4509	2
Transportation Equipment	25%	4582	2
Wood Products	2%	4435	2
Miscellaneous	7%	4619	2
Total	100%		
Average		4587	2

* Source: Energy use analysis (chapter 6 of this TSD).

** Source: Expert opinion.

Table 11.3.21 Residential Sector Annual Hours of Lamp Use and Starts per Day

Building Type	Room Type	GSFL Probability	GSFL Hrs	IRL Probability	IRL Hrs	Starts Per Day*
Single Family Detached	Basement(s)	5.386%	581	0.691%	584	1
	Bathroom(s)	4.040%	581	4.837%	584	7
	Bedroom(s)	2.488%	581	4.469%	584	3
	Closet(s)	3.706%	509	0.783%	511	1
	Dining Room(s)	0.526%	690	1.889%	694	2
	Exterior(s)	1.385%	945	27.365%	949	5
	Garage(s)	26.163%	545	0.000%	548	2
	Hall(s)	1.436%	545	7.740%	548	5
	Kitchen(s)	20.314%	836	13.268%	840	7
	Laundry/Utility Room(s)	5.027%	545	0.645%	548	2
	Living/Family Room(s)	2.886%	727	10.365%	730	4
	Office(s)	1.744%	690	3.133%	694	3
	Other/Unknown	6.156%	363	3.686%	365	2
Single Family Attached	Basement(s)	0.604%	618	0.078%	621	1
	Bathroom(s)	0.309%	581	0.370%	584	7
	Bedroom(s)	0.192%	581	0.345%	584	3
	Closet(s)	0.224%	509	0.047%	511	1
	Dining Room(s)	0.043%	690	0.155%	694	2
	Exterior(s)	0.065%	981	1.279%	986	5
	Garage(s)	0.856%	545	0.000%	548	2
	Hall(s)	0.113%	545	0.607%	548	5
	Kitchen(s)	1.794%	836	1.172%	840	7
	Laundry/Utility Room(s)	0.235%	509	0.030%	511	2
	Living/Family Room(s)	0.216%	727	0.775%	730	4
	Office(s)	0.086%	654	0.155%	657	3
	Other/Unknown	0.576%	363	0.345%	365	2

Building Type	Room Type	GSFL Probability	GSFL Hrs	IRL Probability	IRL Hrs	Starts Per Day*
Multifamily	Basement(s)	0.281%	509	0.036%	511	1
	Bathroom(s)	0.768%	581	0.920%	584	7
	Bedroom(s)	0.442%	581	0.794%	584	3
	Closet(s)	0.597%	472	0.126%	475	1
	Dining Room(s)	0.085%	690	0.307%	694	2
	Exterior(s)	0.110%	981	2.182%	986	5
	Garage(s)	1.280%	545	0.000%	548	2
	Hall(s)	0.221%	545	1.190%	548	5
	Kitchen(s)	4.860%	836	3.174%	840	7
	Laundry/Utility Room(s)	0.281%	472	0.036%	475	2
	Living/Family Room(s)	0.618%	727	2.218%	730	4
	Office(s)	0.201%	654	0.361%	657	3
	Other/Unknown	0.361%	327	0.216%	329	2
Mobile Home	Basement(s)	0.069%	690	0.009%	694	1
	Bathroom(s)	0.264%	581	0.316%	584	7
	Bedroom(s)	0.164%	581	0.294%	584	3
	Closet(s)	0.147%	509	0.031%	511	1
	Dining Room(s)	0.031%	690	0.111%	694	2
	Exterior(s)	0.072%	945	1.420%	949	5
	Garage(s)	0.379%	581	0.000%	584	2
	Hall(s)	0.035%	545	0.187%	548	5
	Kitchen(s)	1.200%	836	0.783%	840	7
	Laundry/Utility Room(s)	0.347%	545	0.045%	548	2
	Living/Family Room(s)	0.208%	763	0.748%	767	4
	Office(s)	0.020%	654	0.036%	657	3
	Other/Unknown	0.387%	327	0.231%	329	2

Building Type	Room Type	GSFL Probability	GSFL Hrs	IRL Probability	IRL Hrs	Starts Per Day*
	Total	100%		100%		
	Average		634		763	3.80

Probabilities and hours of use were calculated as part of the life cycle cost analysis (chapter 6 of this TSD).

* Source: Expert opinion.

11.3.7 Rare Earth Costs

As described in section 11.1, DOE considered the impact of possible changes in REO prices in its GSFL shipments modeling. REOs are used in fluorescent lamp phosphors at higher concentrations in more-efficient models. REOs saw large price increases in the third quarter of 2010 and into 2011, which have now largely corrected themselves, as shown by the GSFL tri-band phosphor price index shown in Figure 11.3.5 and described in appendix 11B. This volatility has resulted in significant uncertainty about the potential long-term impact on GSFL prices.

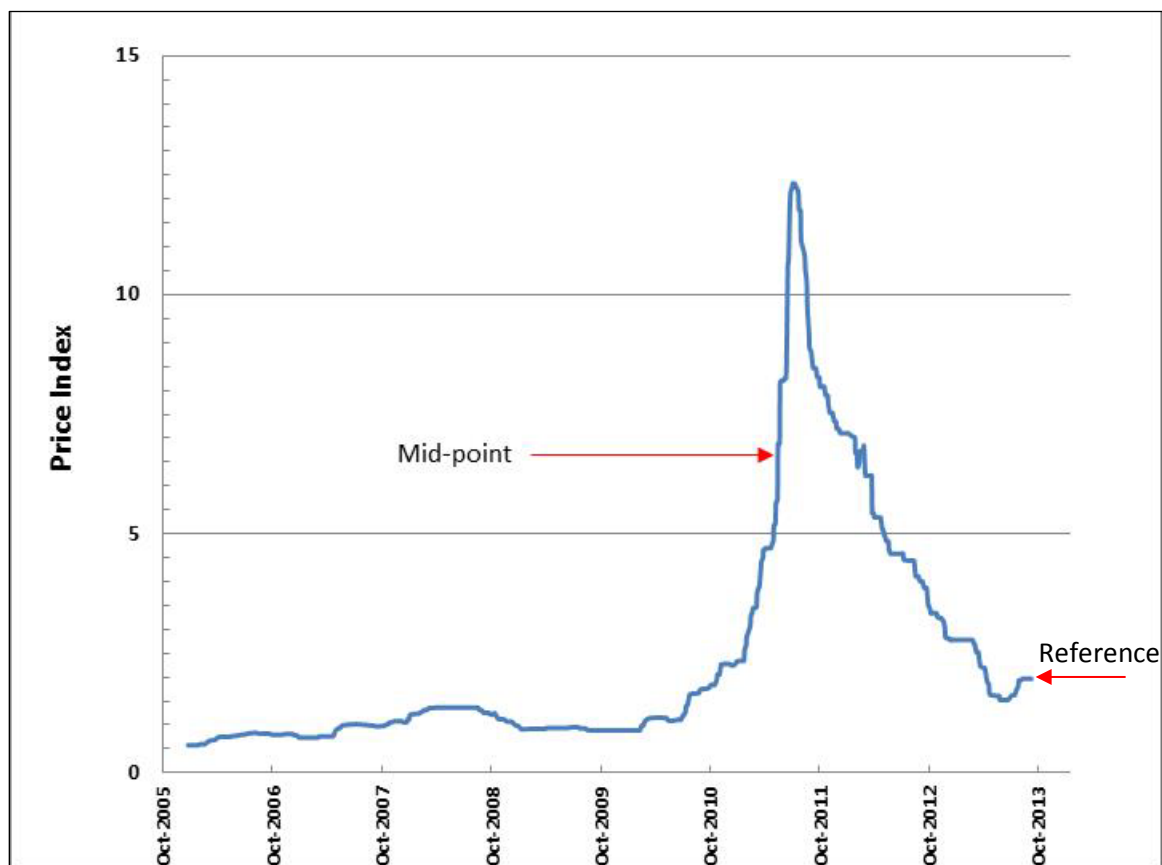


Figure 11.3.5 Inflation-Adjusted, Tri-band Phosphor REO Price Index for GSFLs

Given the large uncertainty caused by such price volatility, DOE modeled GSFL lamp prices assuming two different REO price scenarios detailed in appendix 11B: a reference (best estimate) scenario, which reflects the REO prices with the most recent price data (October 2013), and a high scenario (shown as mid-point in Figure 11.3.5), which reflects the mid-point REO

price between the 2011 peak price and the 2006 – 2009 baseline average price. Given the lack of any clear consistent price trend, in any given scenario, the REO real price was assumed to remain constant over the analysis period.

11.4 ALTERNATIVE SCENARIOS

11.4.1 Overview

In addition to determining the best estimates of the impacts of the five trial standards levels described in the introduction to this chapter (section 11.1), DOE conducted alternative analyses to gauge the importance of various assumptions on the shipments and NIA. Alternative analyses that affect the NIA only are described in chapter 12 of this TSD. This section describes the analyses that affect shipments, and, therefore, also the NIA. As summarized in Table 11.4.1 and Table 11.4.2, these analyses explore the model sensitivity to uncertainties in REO and Xenon prices, and the inclusion of modeled lamp options for GSFL that are not currently available on the market (see chapter 5 of this TSD). The alternative scenarios also assess the impacts of controls adoption and LED incursion for GSFL and IRL, and standards-induced product class switching (see section 11.4.4) for GSFL. A 9-year analysis period was also considered. Results of the alternative scenarios are presented in section 11.5.2.

Table 11.4.1 summarizes the model configuration for the alternative scenarios for GSFL and Table 11.4.2 summarizes the model configuration for alternative scenarios for IRL. As shown, an individual scenario tests the effect of modifying only one scenario variable. The effect is determined by comparing the results of the alternative scenario model runs to the standard best-estimate scenario model runs, which hold all variables at their reference values.

Table 11.4.1 Definition of Best Estimate and Alternative Scenarios for GSFL

Scenarios	Scenario Name	Description
Best Estimate	Reference	Reference values for REO prices, controls adoption and LED incursion. Includes modeled baseline lamps and allows for standards-induced product class switching
Sensitivity Analyses	High REO Price	High REO prices as described in section 11.3.7 and appendix 11B, all other parameters same as Reference scenario
	Market Minimum Efficacy	Does not include modeled baseline lamps, all other parameters same as Reference scenario*
Impact Analyses	Fixed Controls	Holds controls adoption fixed at current rates as described in appendix 11A, all other parameters same as Reference scenario
	No Standards-Induced Product Class Switching	Does not allow standards-induced switching between the lamp types in the model; all other parameters same as Reference scenario
	No LEDs	LED market share held at 2013 levels for entire analysis period as described in section 11.4.2, all other parameters same as for Reference scenario
	9-Year Analysis	Analysis period of 2017-2025 as described in section 11.4.6, all parameters same as for Reference Scenario

* There are currently no 8-foot RDC HO, T5 MiniBP SO or T5 MiniBP HO lamps on the market with efficacies at the baseline level. This scenario prohibits the consumer choice module from selecting baseline level lamps.

Table 11.4.2 Definition of Best Estimate and Alternative Scenarios for IRL

Scenarios	Scenario Name	Description
Best Estimate	Reference	Reference values for lamp life, Xe price, controls adoption and LED incursion
Sensitivity Analyses	IRL Short Life	Assumes EL 1 is met with a short-lived lamp as described in section 11.4.5, all other parameters same as Reference scenario
	High Xe Price	High xenon prices, all other parameters same as Reference scenario
Impact Analyses	Fixed Controls	Holds controls adoption fixed at current rates as described in appendix 11A, all other parameters same as Reference scenario
	No LEDs	LED market share held at 2013 levels for entire analysis period as described in section 11.4.2, all other parameters same as Reference
	9-Year Analysis	Analysis period of 2017-2025 as described in section 11.4.6, all parameters same as Reference scenario

As indicated in the table, Appendix 11A describes the analysis used to generate DOE's best estimate of the future penetration of lighting controls. Further information on the best-estimate and alternative assumptions about REO prices is contained in appendix 11B. The Market Minimum Efficacy scenario is described in section 11.4.2. The impact of the LED incursion is described in section 11.4.3. Section 11.4.4 describes the no standards-induced product class switching scenario. The alternative scenarios for IRLs are discussed in section 11.4.5 and 11.4.6, and the 9-year analysis is discussed in section 11.4.6

11.4.2 Market Minimum Efficacy Sensitivity Analysis

As discussed in chapter 5 of this TSD, DOE believes that there are no lamps currently available at the baseline EL, and that all lamps on the market currently exceed the baseline EL, for the following GSFL lamp types: 8-foot RDC HO, T5 SO, and T5 HO. In its reference shipments analysis, DOE assumed that products would begin to be manufactured at the baseline EL in the absence of standards; therefore, the consumer choice module assigns market share to the baseline lamp options in the reference analysis. The Market Minimum Efficacy alternative scenario assumes that no such baseline lamps are manufactured during the analysis period, so the market share of these lamp options is fixed at zero. This was implemented in the model by setting the acceptance factors for the baseline lamps to zero in Table 11.3.14 - Table 11.3.16.

11.4.3 Light Emitting Diode Impact Determination

As discussed in section 11.2.2.1, DOE assumes in its reference scenario that LED lighting technology will penetrate GSFL/IRL markets. To simplify the shipments model, DOE does not include LEDs as a choice in the consumer choice model, but rather models LEDs as an exogenous effect on the GSFL and IRL markets. The lumen demand satisfied by LEDs in each year is determined by a logistic curve, discussed in this section and in section 11.2.1.1, with the remaining lumen demand allocated to covered products by the consumer choice module as discussed in section 11.2.1.2.

The logistic curve that characterizes LED incursion, assumed to be a Bass adoption curve (Eq. 11.3), is based on the analysis in the SSL report¹. The SSL report projects the percentage of lumen demand (lm-hr/year) fulfilled by LEDs between 2010 and 2030 for a variety of lamp categories, including linear fluorescent and reflector lamps, in each sector. DOE used the SSL forecasts for LED incursion into the residential and commercial GSFL market in this analysis, extrapolating out through 2046. The commercial forecast was assumed to cover both the commercial and industrial sectors for simplicity, since the forecast for LED incursion into the industrial GSFL market was nearly identical to the commercial forecast. The SSL report used a single curve for all sectors for IRLs, which DOE used in this analysis. These curves were then extrapolated out to the end of the analysis period.

Figure 11.4.1 shows the growth in the percentage of the GSFL and IRL markets that DOE expects to be serviced by LEDs over the shipments analysis period.

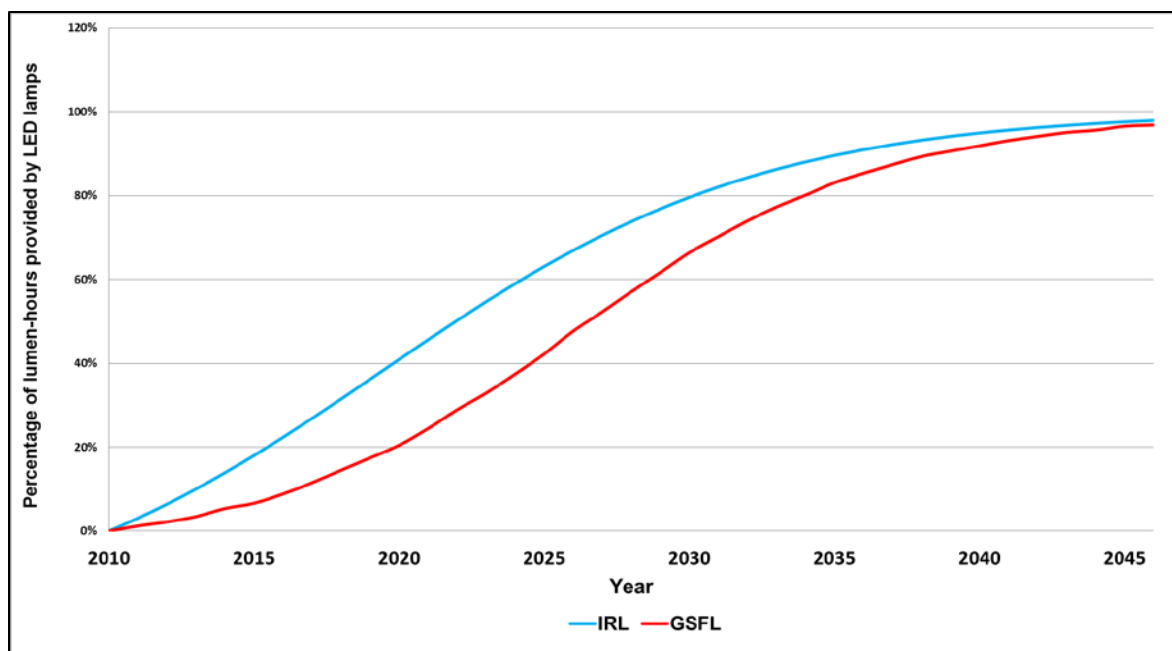


Figure 11.4.1 LED Incursion Curve Projections for GSFLs and IRLs, Best Estimate

DOE used the incursion curves shown in Figure 11.4.1 to project GSFL and IRL lumen capacity (teralumens) displaced by LEDs over the analysis period. Figure 11.4.2 shows DOE's best estimate of the IRL and GSFL lumen capacity displaced by LEDs (light blue and dark blue, respectively) and the lumen capacity expected to remain as IRL and GSFL (light green and dark green, respectively). As revealed by Figure 11.4.1 and Figure 11.4.2, while the LED incursion is expected to essentially eliminate both categories of lamps over the analysis period, the total impact on lamps shipments is expected to be much larger for GSFLs, because of the much larger size of their market.

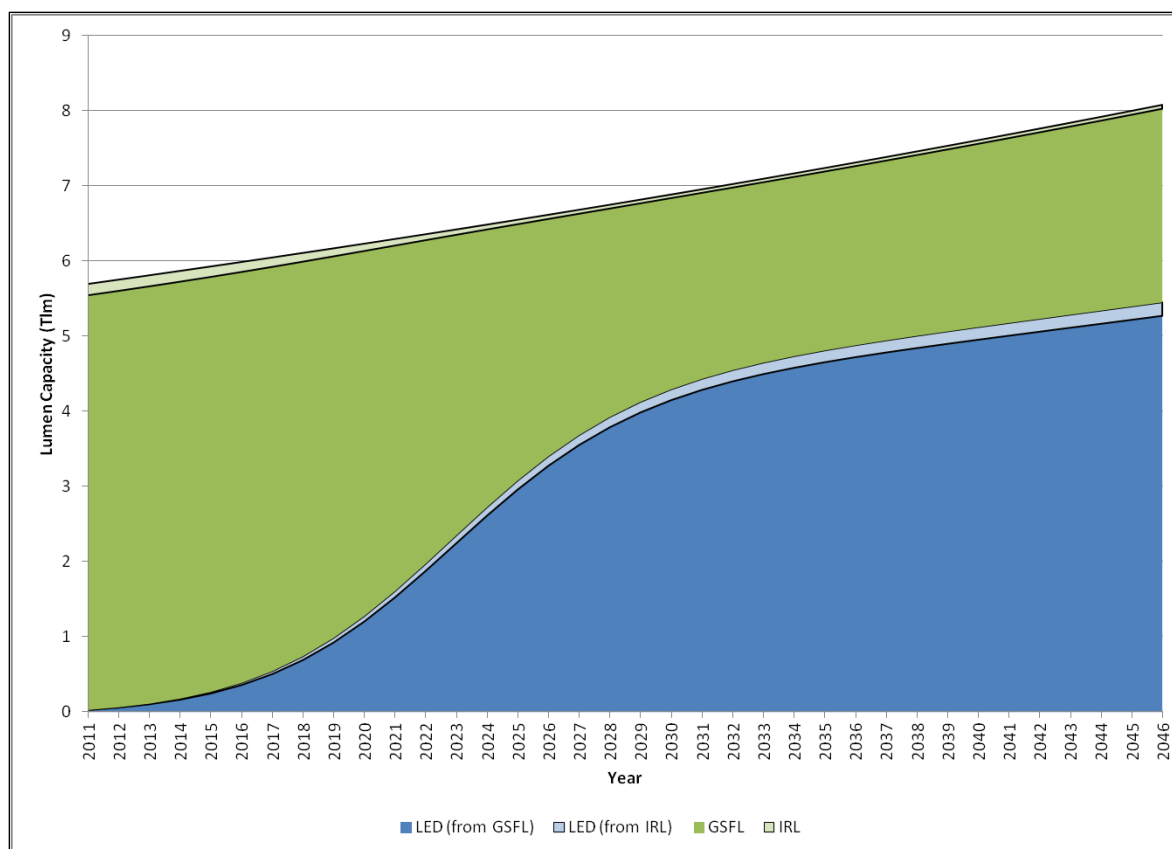


Figure 11.4.2 Lumen Capacity of GSFL, IRL, and Combined GSFL and IRL displaced by LED (Total LED), Best Estimate

11.4.4 No Standards-Induced Product Class Switching

As discussed in section 11.2.2.4 and elsewhere in this chapter, the shipments model for GSFLs allows for the possibility that consumers will switch between lamp types owing to economic considerations. In the base case, these market shifts occur relatively slowly in the model. However, if a potential standard causes a substantial increase in the first costs associated with one lamp type relative to another, the shipments model tends to project a more rapid shift in market share to the newly more cost-effective lamp type. In this analysis, DOE refers to this phenomenon as *standards-induced product class switching*^o. To gauge the effect of such switching on the impact of each TSL, DOE considered an alternative scenario in which the annual shipments for each GSFL lamp type were held fixed at their base-case values. By comparing the results of this scenario to the reference scenario, it is possible to estimate the effect that product class switching has on each TSL.

^o It is important to note that this product class switching refers only to switching between the different aggregated lamp types. The model does not consider the possibility that consumers will switch between product classes with different color temperatures in response to standards, since DOE believes that lamps of different color temperatures are generally used in different applications.

11.4.5 Alternative Short-Lifetime Incandescent Reflector Lamp Technology

Chapter 5 describes the possibility that manufacturers will respond to an amended IRL standard set at EL 1 by producing lamps with reduced lifetimes. In that chapter DOE identified a representative short-lived lamp option that would meet a TSL 1 standard. The lifetime and O&M cost for that alternative standards-compliant lamp, as used in the shipments analysis and the NIA, are documented in Table 11.4.3, along with the properties of the longer-lived reference lamps used in DOE's best-estimate scenario. Because the alternative short-lifetime lamp is very similar to the baseline lamp option, DOE assumed that its price and wattage is the same as the baseline lamp's. The alternative IRL technology analysis includes all of the lamp options listed in Table 11.4.3 in the consumer choice model, with the alternative model being available only after the 2017 compliance year.

Table 11.4.3 IRL Lamp Properties in an Alternative Scenario with Reduced-Lifetime Lamps that Meet a TSL 1 Standard

Lamp Technology Assumption	Initial Light Output (lumens)	Efficacy (lm/W)	Rated Wattage	Wattage**	Rated Lamp Life (hours)	Lamp Life** (hours)	Lamp Life** (years)
Reference technology 1*	1018	18.5	55	51.8	4200	7781	10.2
Reference technology 2*	1036	18.5	56	52.8	2500	4632	6.1
Alternative technology, short lamp life	1124	18.7	60	56.5	1046	1938	2.5

* The reference technologies are the lamp option that DOE determined to be most representative of lamps able to meet an IRL standard set at TSL 1 in the engineering analysis, see Table 9.3.14.

**Corrected for average dimming effects.

11.4.6 High Xenon Price

As discussed in appendix 7C, DOE modeled the impact on IRL prices of an increase in the price of xenon gas, which is commonly used as a fill gas for IRLs. In the shipments analysis and NIA, DOE considered an alternative scenario in which the price of xenon increased by a substantial factor. Since the future price of xenon is highly uncertain, DOE considered a scenario in which the price of xenon increases by a factor of 10 and remains fixed at that level over the entire analysis period. DOE believes this scenario represents a conservative upper bound on the impact that increased xenon prices might have on the outcomes of the rulemaking.

11.4.7 9-Year Analysis Period

For this rulemaking, DOE undertook an impact analysis using nine, rather than 30, years of product shipments. The choice of a nine-year period is a proxy for the timeline in the Energy Policy and Conservation Act (EPCA) for the review of certain energy conservation standards and potential revision of and compliance with such revised standards^p. This timeframe may not be statistically relevant with regard to the product lifetime, product manufacturing cycles or other factors specific to GSFLs and IRLs. Thus, this information is presented for informational purposes only and is not indicative of any change in DOE's analytical methodology.

11.5 RESULTS

This section presents the results of the shipments analysis for the base case, the standards cases corresponding to each of the TSLs and the alternative scenarios.

11.5.1 Results of Analyses of Trial Standards Levels

Table 11.5.1 presents DOE's best estimates of cumulative shipments of GSFLs and IRLs over the 30-year shipments analysis period (2017 – 2046) for the Base Case and the change in shipments relative to the Base Case for the five TSLs considered in the analysis (see Table 11.1.1, for definitions of the TSLs)

^p EPCA requires DOE to review its standards at least once every 6 years, and requires, for certain products, a 3-year period after any new standard is promulgated before compliance is required, except that in no case may any new standards be required within 6 years of the compliance date of the previous standards. While adding a 6-year review to the 3-year compliance period adds up to 9 years, DOE notes that it may undertake reviews at any time within the 6 year period and that the 3-year compliance date may yield to the 6-year backstop. A 9-year analysis period may not be appropriate given the variability that occurs in the timing of standards reviews and the fact that for some consumer products, the compliance period is 5 years rather than 3 years.

Table 11.5.1 Best Estimate of Cumulative Shipments of GSFLs between 2017-2046, for Base Case and change in Shipments Relative to Base Case for All TSLs

Lamp Type	Base Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	Cumulative Shipments (millions)	Change in Shipments Relative to Base Case				
4-foot MBP	5,700	0.0%	0.34%	-2.7%	-24%	-18%
8-foot SP slimline	110	0.0%	-13%	8.6%	71%	24%
8-foot RDC HO	21	0.0%	-8.5%	0.0%	0.0%	-8.5%
4-foot T5, MiniBP SO	410	0.0%	0.83%	28%	250%	210%
4-foot T5, MiniBP HO	660	0.0%	0.27%	-0.01%	-0.12%	0.17%
2-foot U-shaped	230	0.0%	0.0%	-0.0%	-0.0%	-0.0%
Total GSFL*	7,100	0.0%	0.13%	-0.39%	-3.4%	-2.4%

In the following figures, results of the shipments modeling are presented for the Base Case, TSL 3, TSL 4, and TSL 5. In most cases, results for TSL 1 and TSL 2 are visually indistinguishable from the Base Case and have been omitted; all results can be viewed in the NIA spreadsheet tool. Figure 11.5.1 shows DOE's best estimate of the historical and projected shipments of GSFLs, broken down by lamp type. Shipments of all lamp types show a sharp decline by the end of the analysis period due to LED incursion into the GSFL market. Figure 11.5.2 shows projected market shares of standard-output lamp shipments by lamp type over the analysis period. Figure 11.5.3 shows projected market shares of high-output lamp shipments by lamp type over the analysis period. Figure 11.5.4 show the projected shipments-weighted average lamp efficacy for all lamp types.

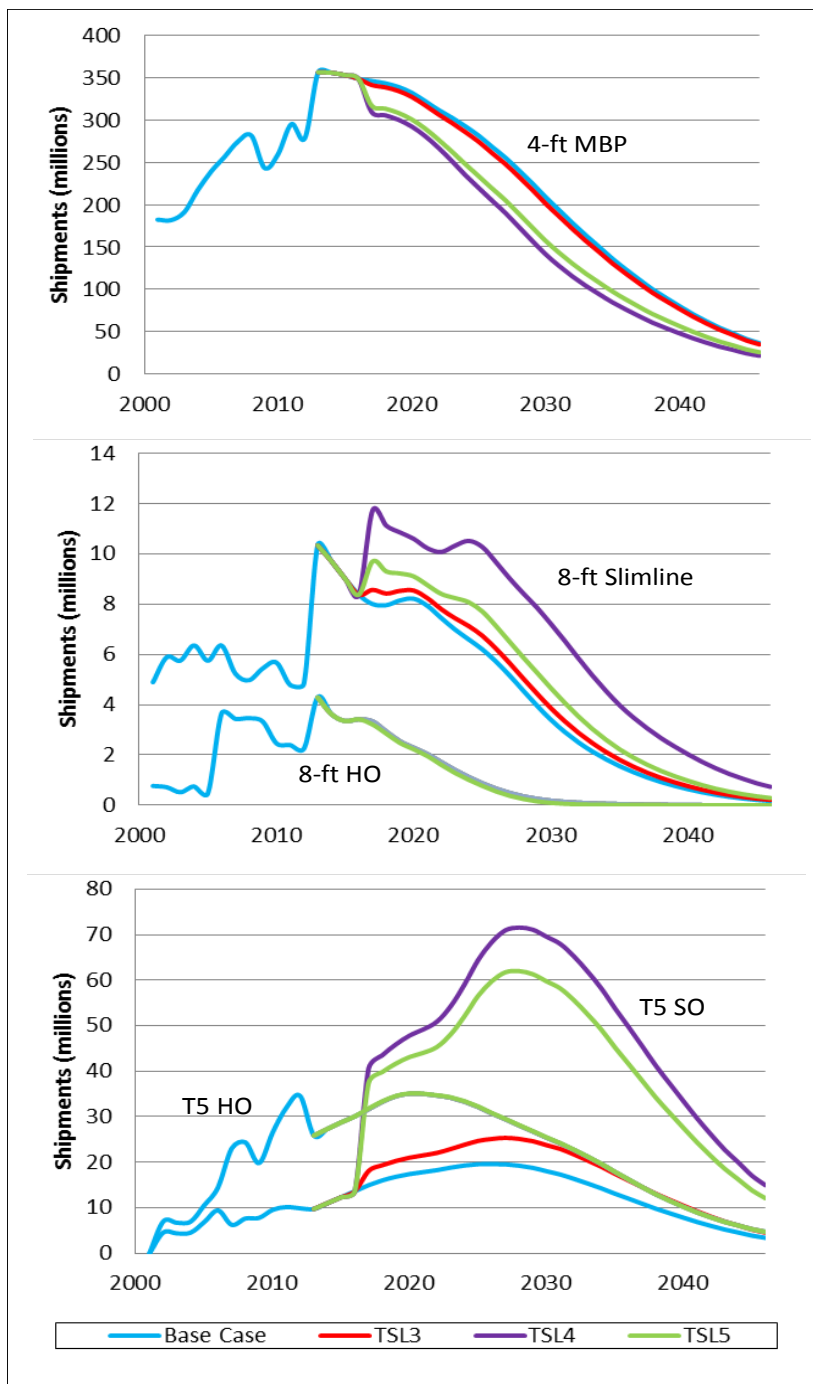


Figure 11.5.1 Historical and Projected Shipments of GSFLs by Lamp Type, for the Reference Scenario^q

^q In most cases the shipments for the Base Case, TSL 1, and TSL 2 are indistinguishable on the figure, therefore, only the Base Case, TSL 3, TSL 4, and TSL 5 shipments are presented.

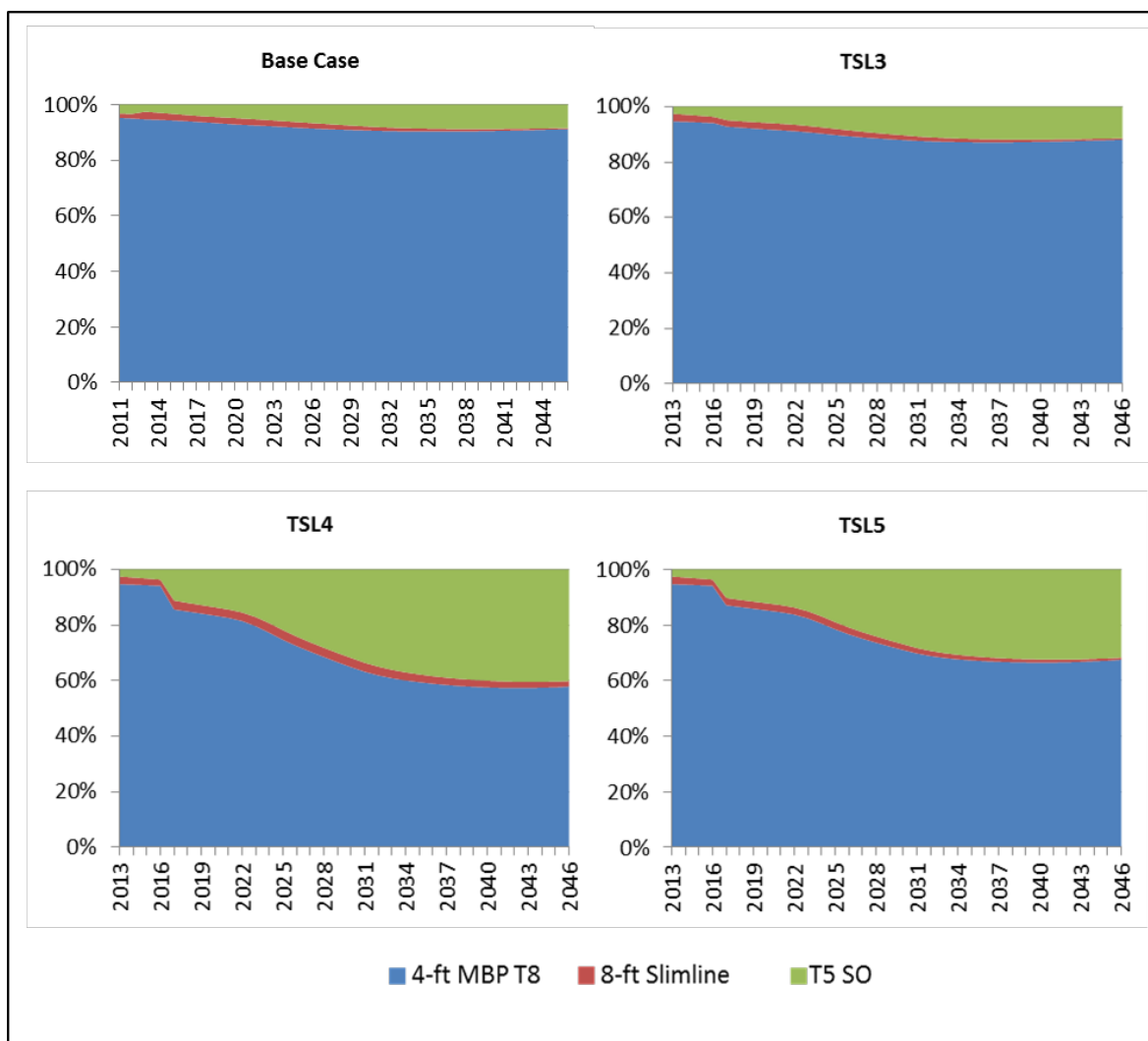


Figure 11.5.2 Projected Market Shares of Standard Output Lamp Shipments by Lamp Type, for Base Case, TSL 3, TSL 4, and TSL 5 in Reference Scenario

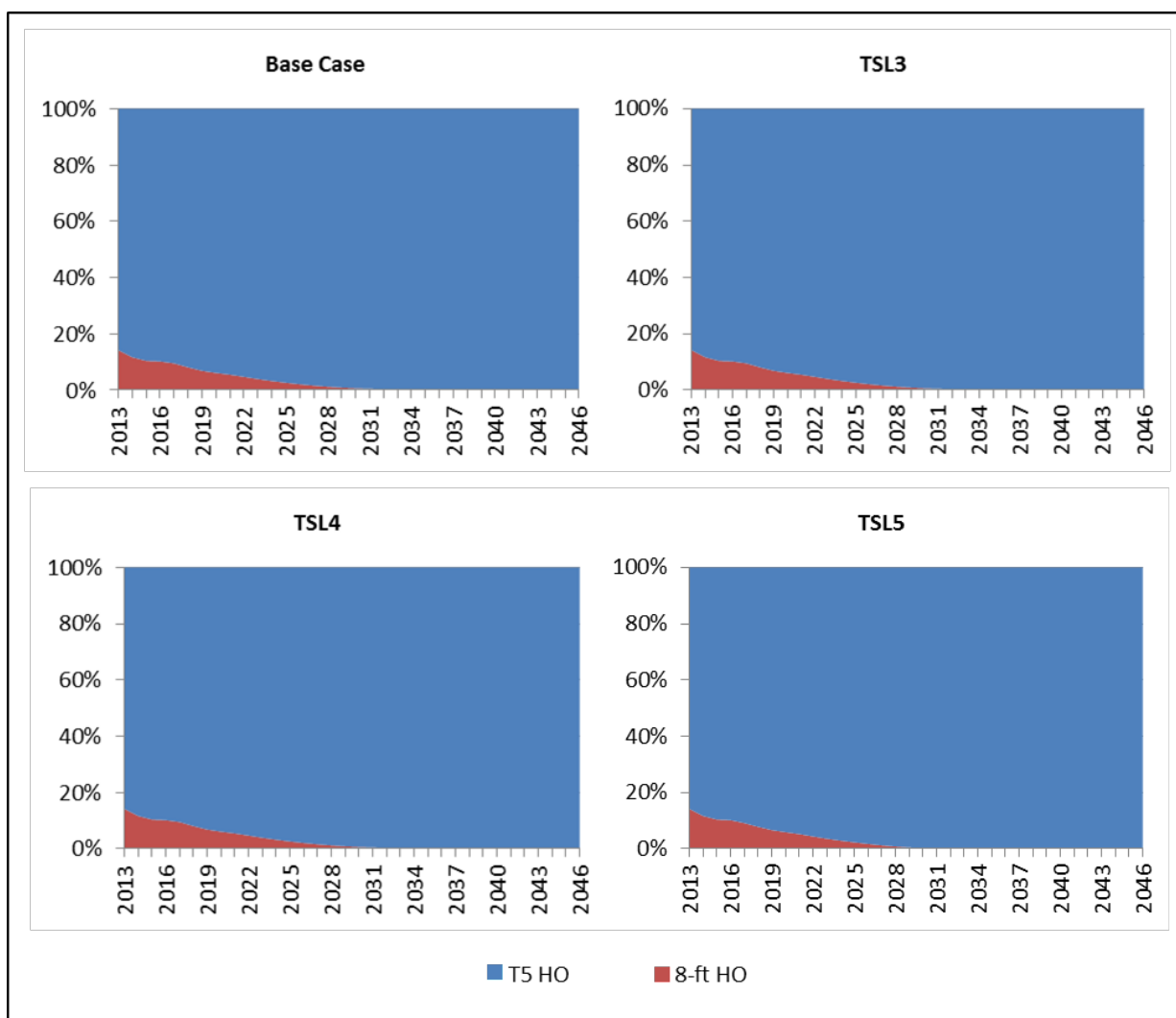


Figure 11.5.3 Projected Market Shares of High Output Lamp Shipments by Lamp Type, for Base Case, TSL 3, TSL 4, and TSL 5 in Reference Scenario

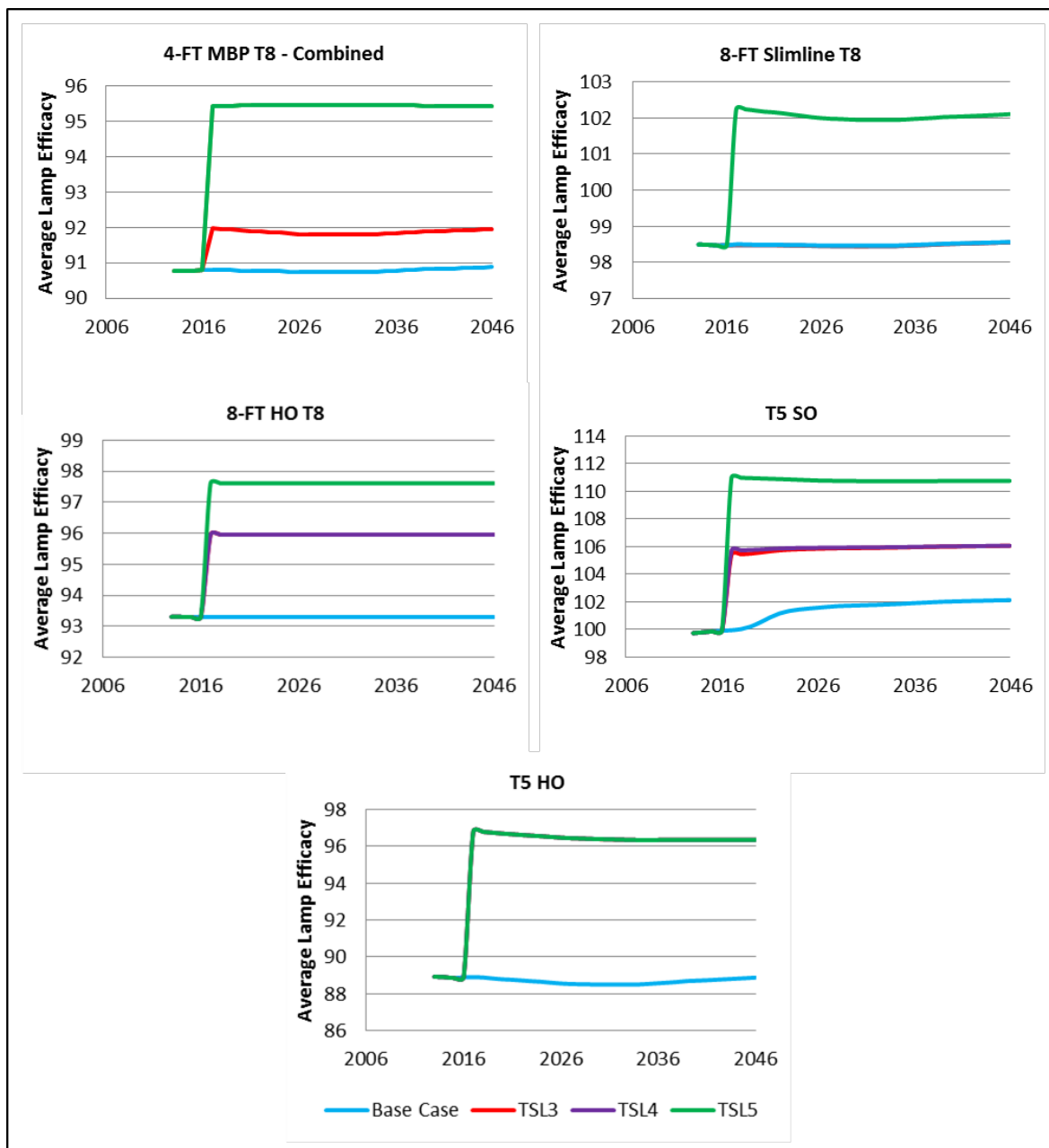


Figure 11.5.4 Projected Average Lamp Efficacy for GSFL Lamp Types for Base Case, TSL 3, TSL 4 and TSL 5 in Reference Scenario

Table 11.5.2 shows DOE's best estimates of cumulative shipments for IRL and the change in shipments relative to the Base Case for TSL 1.

Table 11.5.2 Best Estimate of Cumulative Shipments of IRLs between 2017-2046, for Base Case and change in Shipments Relative to Base Case for TSL 1.

Lamp Type	Base Case	TSL 1
	Cumulative Shipments (millions)	Change in Shipments Relative to Base Case
Standard spectrum; > 2.5 inch diameter	230	-20%

Figure 11.5.5 shows DOE's best estimate of the historical and projected shipments of IRLs, broken down into residential, commercial, and total shipments. Again, both the base case and the standards case show a sharp decline in shipments due to the expected market incursion of LEDs, which is expected to occur faster in the IRL market than the GSFL market (see Figure 11.4.1). The noticeable dip in shipments after the 2017 compliance year for TSL1 occurs because the TSL1 lamp options have much longer lifetimes than the baseline options, so fewer replacement lamps are shipped for a period until the stock turnover regains equilibrium.

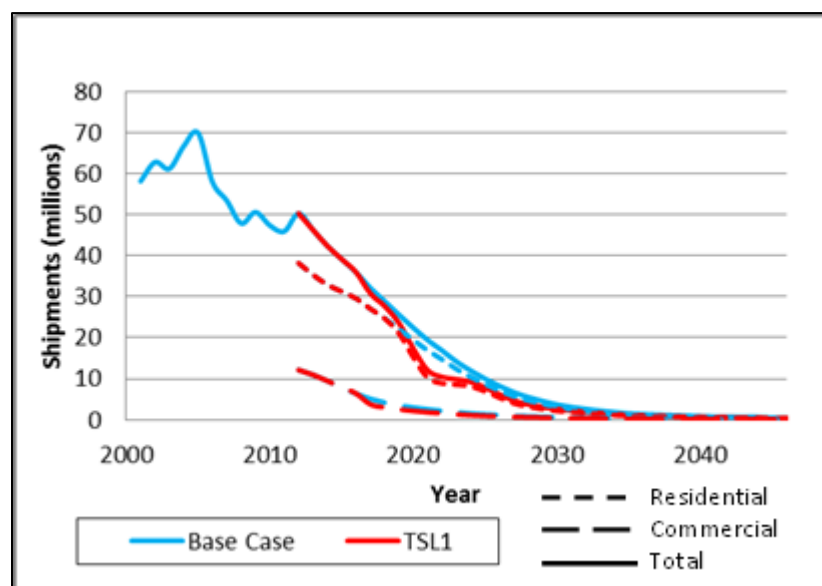


Figure 11.5.5 Historical and Projected Shipments for IRLs for Reference Scenario^r

^r In some cases, the change in shipments between the TSL and base case is so small it is indistinguishable on the figure. In that case, the higher standard level overwrites the lower.

Figure 11.5.6 shows the projected lamp efficacy for IRLs in the commercial and residential sector for the base case and TSL 1

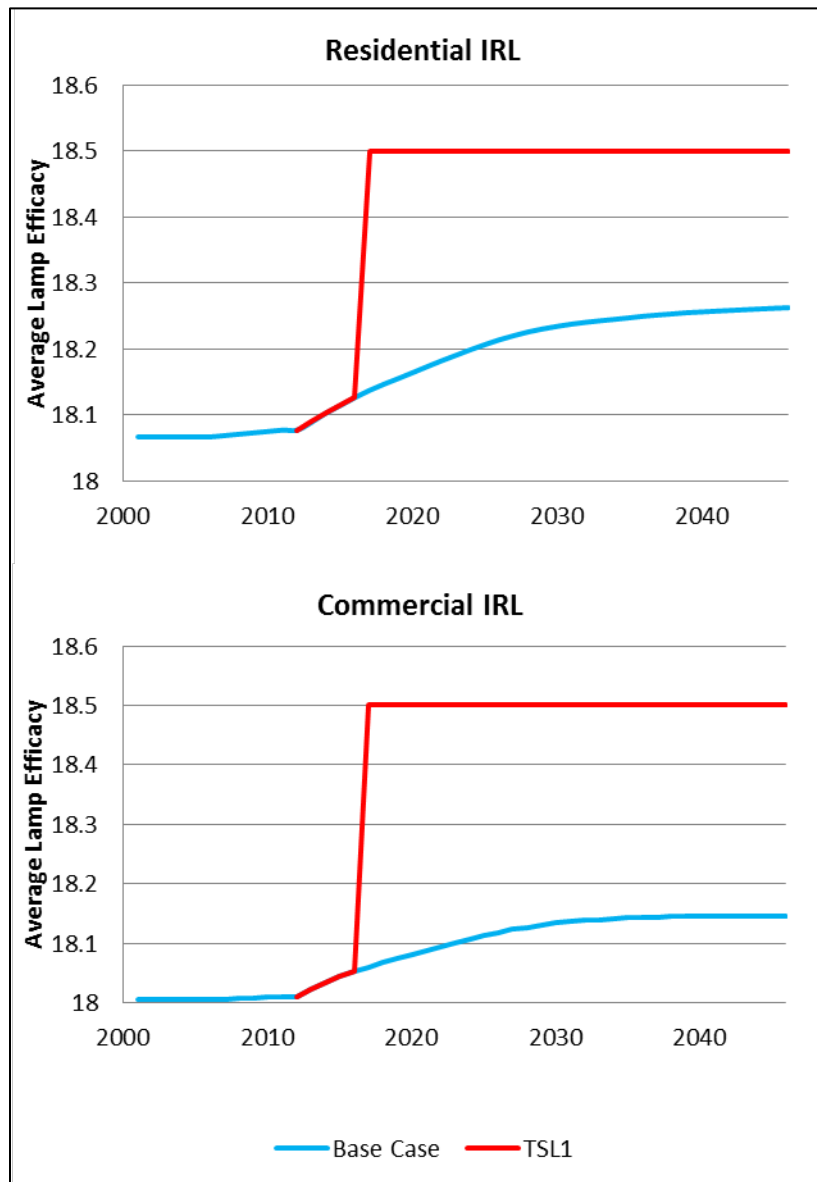


Figure 11.5.6 Projected Lamp Efficacy for Residential and Commercial IRL Lamps for Base Case and TSL in Reference Scenario

11.5.2 Results of the Alternative Scenarios

This section presents the results of the Alternative Scenarios explored by DOE. Table 11.5.3 summarizes the base case cumulative shipments for all of the sensitivity analyses and reports the change from the base case for all TSLs for GSFL. Table 11.5.4 presents the result for the sensitivity analyses for IRL.

Table 11.5.3 GSFL Cumulative Shipments in the Base Case and percentage change from Base Case for Sensitivity Analyses for all TSLs, from 2017 – 2046

	Base Case	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Scenarios	Cumulative Shipments (millions)	Change in Shipments Relative to Base Case				
Reference	7,141	0.0%	0.13%	-0.39%	-3.4%	-2.4%
High RE Price	7,079	0.0%	0.35%	-0.52%	-3.7%	-2.2%
Market Minimum Efficacy	7,141	0.0%	0.13%	-0.39%	-3.4%	-2.4%
9-year Analysis	3,540	0.0%	0.13%	-0.30%	-2.4%	-1.7%

Table 11.5.4 IRL Cumulative Shipments in the Base Case and percentage change from Base Case for Sensitivity Analyses for TSL 1, from 2017 – 2046

	Base Case	TSL 1
Scenarios	Cumulative Shipments (millions)	Change in Shipments Relative to Base Case
Reference	230	-20%
IRL Short Life	230	-7.6%
High Xe Price	230	-16%
9-year Analysis	180	-18%

As discussed in section 11.4, DOE also utilized several alternative scenarios, which it termed impact analyses, which eliminate certain market trends that DOE believes are likely to occur over the analysis period. DOE does not interpret these analyses as reflecting uncertainty in the analysis; rather, these analyses simply show the overall impact of future market trends relative to a scenario in which the trends did not occur. Since it is informative to understand the impacts of assumed future market trends on the analysis, the results of the impact-analysis scenarios for the shipments analysis are summarized in the following.

Eliminating standards-induced product class switching removes all shifts in the market shares of the different lamp types in the various standards cases, relative to the base case. In that case all percentages presented in Table 11.5.1 become zero.

Assuming fixed controls increases shipments by approximately 4% compared to the reference scenario for the base case, and TSLs 1-4. For TSL5 shipments are increased approximately 2% compared to the reference scenario.

The greatest impact arises from assuming LEDs do not encroach on the GSFL market. In this scenario, shipments approximately double for the base case and all TSLs compared to the reference scenario when LEDs are assumed to stay at their current market shares.

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CHAPTER 12. NATIONAL IMPACTS ANALYSIS

12.1 INTRODUCTION

This chapter describes the method the U.S. Department of Energy (DOE) used to estimate the national impacts of five trial standard levels (TSLs) for covered general service fluorescent lamps (GSFLs) and one TSL for incandescent reflector lamps (IRLs). In the national impacts analysis (NIA), DOE assessed the cumulative national energy savings (NES) of products shipped during a 30-year analysis period (2017 – 2046) and the net present value (NPV) of the total consumer economic impacts, by projecting energy consumption and consumer costs in a series of analysis cases that assumed each of the TSLs in turn were adopted in this rulemaking. DOE then compared each TSL case to a base case, in which standards were assumed to remain at the current level. The TSL definitions are presented in chapter 10 of this TSD. In addition to NES and NPV, this chapter reports DOE's estimate of the monetary value to the nation of the cumulative energy savings and the total cumulative change in equipment costs resulting for each of the TSLs.

DOE performs all NIA calculations using a Microsoft Excel® spreadsheet which is available on regulations.gov, docket number EERE–2011–BT–STD–0006 at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006. Details regarding, and instructions for using, the NIA spreadsheet are provided in appendix 12A.

Table 12.1.1 summarizes the inputs to the NIA spreadsheet model. A brief description of the data is given for each input.

Table 12.1.1 Summary of NES and NPV Inputs

Input	Data Description
Shipments	Annual shipments from the GSFL and IRL shipments model (see chapter 11 of this TSD)
Stock of lamps	Modeled from historical data and shipments projections (see chapter 11 of this TSD)
Effective date of standard	2017
Analysis period	For products shipped from 2017 through 2046
Maximum lamp lifetime	Assumed to be 35 years to accommodate GSFLs in the residential sector. To account for lamps that live this long, the NES calculation must include energy consumption and lamp disposal costs for some lamps out to 2080.
Lamp and ballast characteristics	Wattage, first cost, installation cost, disposal cost (see chapter 11 of this TSD)
Lamp Prices	Prices of lamps, adjusted for price learning in each year (see chapter 11 of this TSD)
Projected electricity prices	From <i>AEO2013</i> to 2040 and extrapolated beyond 2040 (see chapter 11 of this TSD)
Site-to-primary electricity conversion	Generated by the NEMS version corresponding to the 2013 <i>AEO</i> (to 2040) and extrapolated beyond 2040
Rebound effect	Percent of total energy savings in the commercial and residential sector (see appendix 12B)
Discount rate	Real 3 and 7 percent
Present year	Future costs and savings are discounted to the year 2013

The following sections describe in detail the methodology and inputs for the NIA. Section 12.2 discusses DOE's methods for calculating national energy consumption in the

base-case and standards cases, and the resulting NES of the standards cases with respect to the base case. Section 12.3 discusses the NPV calculation method. Section 12.4 presents the NES and NPV results for the different TSLs, and under various scenarios.

12.2 NATIONAL ENERGY SAVINGS

This section describes DOE's calculation of the NES for the two categories of lamps (GSFL and IRL) under the TSLs considered in this analysis.

12.2.1 Primary Energy Savings

The annual NES quantifies the difference in energy use between the base case and a standards case in a given year:

$$NES(y) = (AEC_{base}(y) - AEC_{std}(y)) \times RF \quad \text{Eq. 12.1}$$

Where:

$NES(y)$ = national energy savings in year y^a (quads),
 $AEC_{base}(y)$ = base case annual national energy consumption at the power plant for all lamp types combined in year y (quads),
 $AEC_{std}(y)$ = standards case annual national energy consumption at the power plant for all lamp types combined in year y (quads), and
 RF = rebound rate factor, given by $1 - \text{rebound rate}$ (see appendix 12B).

Positive values of NES correspond to a net energy savings following standards implementation. In other words, if NES is positive, annual energy consumption (AEC) in the standards case is less than AEC in the base case^b.

As discussed in chapter 11 of this TSD, for the purpose of computing the NES, it is not necessary to compute the total installed stock, $S(y)$, of lamps and lamp-and-ballast systems in the United States. The only portion of the stock that is relevant to this calculation is the *operating stock shipped during the analysis period* (OSSDAP), denoted $S'(y)$, with the assumption that $S'(y_{rule} - 1) = 0$, where $y_{rule} = 2017$, the compliance year of the new rule, is the first year of the analysis period. Eq. 12.1 can therefore be expressed as follows:

$$NES(y) = (AEC'_{base}(y) - AEC'_{std}(y)) \times RF \quad \text{Eq. 12.2}$$

^a Note that the time variable y is a discrete variable representing any year between 2017-2080 and is not continuous. For quantities that depend on y , the notation $f(y)$ is used, instead of f_y , to avoid confusion with other subscripts.

^b Following the example of the 2011 fluorescent lamp ballast final rule and for reasons given therein, DOE is assuming that the effects of heating, ventilating, and air conditioning (HVAC) interactions on NES are negligible.

Where:

$AEC'_{base}(y)$ = base case annual national energy consumption of the OSSDAP at the power plant for all lamp types combined in year y (quads), and
 $AEC'_{std}(y)$ = standards case annual national energy consumption of the OSSDAP at the power plant for all lamp types combined in year y (quads).

The cumulative national energy savings is the sum of each $NES(y)$ for all operating stock shipped during the 30-year analysis period (2017 – 2046). The analysis tracks the energy use of the stock shipped during the analysis period until the longest-lived unit shipped in 2046 is assumed to be retired, in 2080. The cumulative NES is computed as follows:

$$NES_{cum} = \sum_y NES(y) \quad \text{Eq. 12.3}$$

Where:

NES_{cum} = cumulative national energy savings (quads).

DOE computed the AEC for IRLs by summing over the OSSDAP of each lamp option, as reflected in the following equation:

$$AEC'_{IRL}(y) = \left(\sum_l S'_{l,IRL}(y) \times UEC_{l,IRL}(y) \right) \times SP(y) \quad \text{Eq. 12.4}$$

Where:

$S'_{l,IRL}(y)$ = the OSSDAP of IRL option l in year y (number of units),
 $UEC_{l,IRL}(y)$ = the annual unit energy consumption of IRL option l in year y , as described in section 12.2.3.2 (kWh), and
 $SP(y)$ = time variable site-to-power-plant energy conversion factor that converts site electricity use (kWh) to primary energy consumed at the power plant (quads/kWh).

As discussed in chapter 11 of this TSD, DOE computed shipments and stock of GSFLs disaggregated according to a set of ballast options incorporating different technologies and ballast factors, to which the lamps are coupled. Each GSFL lamp type in the model is associated with one or several ballast options. DOE calculated the AEC for GSFL by summing over all of the ballast options:

$$AEC'_{GSFL}(y) = \sum_B AEC'_{B,GSFL}(y) \quad \text{Eq. 12.5}$$

Where:

$AEC'_{B,GSFL}(y)$ = the annual energy consumption by the OSSDAP of GSFLs that are installed on ballasts option B in year y (quads).

The AEC of GSFLs installed on each ballast option was computed in turn by summing over the energy consumption of the various lamp options that are installed on that ballast, as shown by the following equation:

$$AEC'_{B,GSFL}(y) = \left(\sum_l S'_B(y) \times \phi_{l,B}(y) \times UEC_{l,B,GSFL}(y) \right) \times SP(y) \quad \text{Eq. 12.6}$$

Where:

$S'_B(y)$ = the OSSDAP of GSFL installed on ballasts option B , in year y , calculated by the shipments model (number of units),

$\phi_{l,B}(y)$ = the fraction of the OSSDAP of GSFL installed on ballast option B that is represented by lamp option, l ,^c calculated by the shipments model,

$UEC_{l,B,GSFL}(y)$ = average unit energy consumption of lamp option l installed on ballast option B in year y , as described in section 12.2.3.2 (kWh), and

$SP(y)$ is defined after Eq. 12.4.

12.2.2 Full-Fuel-Cycle Energy Savings

DOE has historically presented the NES computed based on the primary energy savings at the power plant, as described in the previous section. Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses full-fuel-cycle (FFC) measures of energy use and emissions in its energy conservation standards analyses.¹ In addition to the primary energy used at the power plant to supply electricity to the site of use and account for transmission and distribution losses, the FFC analysis also accounts for energy consumed up-stream of the power plant in extracting, processing, and transporting or distributing the primary fuels to the power plant, as described in appendix 12C.

As shown in Eq. 12.7, the FFC national energy savings (NES_{FFC}) were obtained by multiplying the primary energy savings (Eq. 12.2) by the FFC multiplier computed for the same year, $\mu(y)$:

$$NES_{FFC}(y) = (AEC'_{base}(y) - AEC'_{std}(y)) \times RF \times \mu(y) \quad \text{Eq. 12.7}$$

Where:

$\mu(y)$ = the FFC multiplier in year y , and
all other variables were defined in Eq. 12.1 and Eq. 12.2.

^c The lamp options that are available for each of the TSLs are discussed in chapter 11 of this TSD.

The cumulative FFC energy savings are calculated by summing the annual savings from 2017 through 2080:

$$NES_{FFC,cum} = \sum_y NES_{FFC}(y)$$

Eq. 12.8

12.2.3 National Energy Savings Inputs

As described in the preceding sections, the following inputs were used for calculating the national energy savings:

- shipments and operating stock shipped during the analysis period,
- average unit energy consumption (*UEC*),
- site-to-power-plant conversion factor (*SP*),
- primary energy to full fuel cycle multiplier for each year of the analysis (μ), and
- rebound rate factor (*RF*).

These inputs are further discussed in the following sections.

12.2.3.1 Shipments and Operating Stock Shipped during the Analysis Period

The shipments model, described in chapter 11 of this TSD, calculated the shipments of the representative lamp types for each year of the 30-year analysis period (2017 through 2046). Based on that analysis, the model developed a description of the OSSDAP through to the end of the lifetime of all lamps contained therein.

12.2.3.2 Average Unit Energy Consumption

DOE calculated the average annual UEC for each GSFL and IRL option by multiplying the average lamp power consumption by the average annual hours of use for that lamp in the sector under consideration. For IRLs, this is simply the rated lamp wattage multiplied by the annual hours of use:

$$UEC_{l,IRL} = \frac{W_{l,IRL} \times \bar{u}_{IRL}}{1000}$$

Eq. 12.9

Where:

$UEC_{l,IRL}$ = the annual UEC of IRL option *l* (kWh),

$W_{l,IRL}$ = the rated wattage of IRL option *l*, corrected for the impact of dimmers, as discussed in chapter 11 of this TSD (W), and

$\bar{u}_{IRL}$ = the average annual hours of use for an IRL in the sector being considered (hours), as presented in chapter 6 of this TSD.

For GSFL, in addition to lamp properties, the UEC also depends also on the ballast factor and ballast luminous efficiency (BLE) for the ballast option being considered:

$$UEC_{l,B,GSFL} = \frac{100 \times RAP_l \times BF_B \times \bar{u}_{GSFL}}{1000 \times BLE_B} \quad \text{Eq. 12.10}$$

Where:

$UEC_{l,B,GSFL}$ = the annual UEC of GSFL option l , when it is coupled to a ballast option B (kWh),

$RAP_{l,GSFL}$ = the reference arc power of GSFL option l , as presented in chapter 11 of this TSD (W),

BF_B = the ballast factor of ballast option B , as presented in chapter 11 of this TSD,

BLE_B = the ballast luminous efficacy of ballast option B , as presented in chapter 11 of this TSD, and

$\bar{u}_{GSFL}$ = the average annual hours of use for a GSFL in the sector being considered (hours).

To compute the average hours of use for GSFL and IRL, DOE computed the averages of the sector-specific hours-of-use distributions presented in chapter 6 of this TSD. When analyzing GSFLs in the combined commercial and industrial sectors, DOE weighted these sectors' distributions using weighting factors computed as described in chapter 11 of this TSD.

As discussed in detail in chapter 11 of this TSD, DOE assumed that lighting controls are installed on an increasing fraction of lamps in the commercial and industrial sectors as a result of building codes (see appendix 11A of this TSD), and assumed a 75 percent compliance rate. DOE further assumed that 26% of GSFL controls systems incorporated dimming ballasts, and that the fraction of IRLs installed on dimmers remains fixed over the analysis period, with the remainder of controls systems based on switching only. To account for the impact of lighting controls on the NES, DOE reduced the UEC by a fixed 30 percent for the stock of lighting in which controls based on switching only were assumed to operate, where the savings estimate was based on a meta-analysis of field measurements of energy savings from commercial lighting controls by Williams et al. (2012).² For controls systems that incorporate dimming, DOE assumed the energy consumption reductions that are detailed in chapter 11 of this TSD.

For each lamp option (whether IRL or GSFL, and regardless of ballast type), the unit energy consumption of lamps installed on switching-only lighting control systems was computed using the following formula:

$$UEC_l(y) = UEC_l \times (1 - LC_{adopt}(y) + LC_{adopt}(y) \times LC_{effect}) \quad \text{Eq. 12.11}$$

Where:

$UEC_l(y)$ = weighted average annual energy consumption (kWh) of lamp option l ,

UEC_l = annual unit energy consumption (kWh) of lamp option l , operating under full power for the average number of hours of use per year, computed using the previous equations,

$LC_{adopt}(y)$ = the lumen capacity fraction of lighting estimated to be operating under switching-only lighting controls in year y , and

LC_{effect} = a parameter describing the effect of switch-based lighting controls on energy consumption, taken to be 0.7.

DOE included two projections of controls adoption. In the reference case, which is DOE's best estimate, controls penetration grows year-by-year in the commercial and industrial sector, as driven by building codes and described in appendix 11A. In the second, alternative scenario, controls penetration was assumed to remain fixed at the same level as the first year in the analysis period. The latter was included to determine the impact of controls on the estimated energy savings from the rulemaking; DOE does not consider the fixed-controls scenario realistic given the strong driving factors for controls adoption.

12.2.3.3 Site-to-Power Plant Conversion Factor

To estimate the energy used at the power plant to supply the electricity used on-site by the two categories of lamps, DOE multiplied the site energy consumption, $UEC_l(y)$, by a site-to-power-plant conversion factor,^d which accounts for average losses associated with the generation, transmission, and distribution of electricity from the fleet of U.S. power plants to the point of use. DOE used annual site-to-power-plant conversion factors based on the version of the National Energy Modeling System (NEMS) that corresponds to the Energy Information Administration's *Annual Energy Outlook 2013 (AEO2013)*.³ The factor changes over time in response to projected changes in generation sources (the types of power plants projected to provide electricity to the country). Figure 12.2.1 shows how the site-to-power plant conversion factor is expected to change during the NES and NPV analysis period.

^d In previous rulemakings the site-to-power-plant conversion factor has been referred to as the *site-to-source conversion factor*. The terminology is modified here to clarify that the analysis only accounts for the energy used at the power plants, but not energy used upstream of the power plants to provide that service. The latter is incorporated in the full-fuel-cycle analysis.

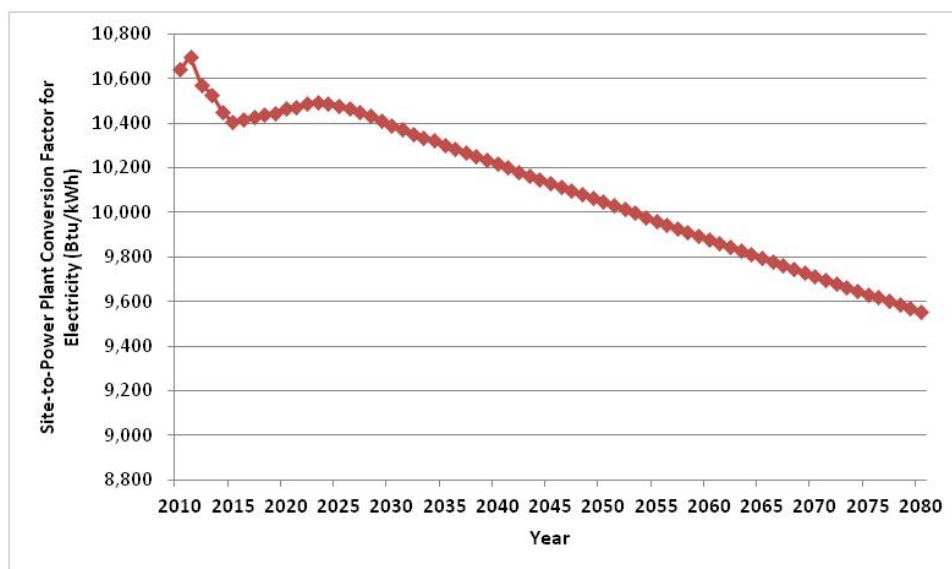


Figure 12.2.1 Site-to-Power Plant Conversion Factor for Electricity

12.2.3.4 Primary Energy to Full-Fuel-Cycle Multipliers

For this analysis, DOE calculated FFC energy savings using a methodology described in appendix 12C. As discussed previously, the FFC energy savings are obtained by multiplying the primary energy savings at the power plant by the FFC multiplier. The estimated FFC multiplier (μ) is essentially constant, ranging between 1.040 and 1.045 from 2017 to 2080.

12.2.3.5 Rebound Rate Factor

DOE generally accounts for the direct rebound effect in its estimates of the NES. DOE received public comment regarding the rebound rates proposed in the framework document for this rulemaking and performed additional analyses to reevaluate the proposed rates based on the most recent available data. Presented in appendix 12B, that analysis reveals no current evidence for lighting rebound in the United States. Therefore, for its *best estimate*, DOE assumes no lighting rebound. However, DOE conducted sensitivity analyses for two additional scenarios to determine the potential impact of alternative assumptions on the rulemaking. In the first alternative scenario, DOE conducted the analysis using the assumptions for rebound rates proposed in the framework document. In its second alternative scenario, DOE assumed the values used for lighting rebound in NEMS. As described in appendix 12B, the latter were based on an estimate of the average rebound rate for a suite of appliances, and the lighting data contained therein were from the early 1990s. The values used in the best estimate and alternative scenarios are summarized in Table 12.2.1.

Table 12.2.1 Rebound Rate Scenarios for GSFL and IRL

Rebound Scenario	Commercial Rebound Rate	Residential Rebound Rate
Best Estimate	0%	0%
Framework assumption	1%	8.5%
High	15%	15%

12.3 NATIONAL NET PRESENT VALUE

12.3.1 Definition

The NPV is the difference between the present value of savings (PVS) in operating cost resulting from the use of more efficient appliances under the standard and the present value of increased total installed costs (PVC) of those appliances. The NPV is described by the following equation:

$$NPV = PVS - PVC$$

Eq. 12.12

Where:

PVS= present value of savings in operating cost (including costs for energy, repair, and maintenance in 2012\$) from all lamps shipped during the analysis period; and

PVC= present value of increase in total installed cost (including costs for equipment, installation, and disposal in 2012\$) from of all lamps shipped during the analysis period.

Under this definition, reductions in operating costs contribute positively to the NPV, while increases in total installed costs contribute negatively to the NPV.

DOE determined the *PVS* and *PVC* according to the following equations:

$$PVS = \sum_y OCS(y) \times DF(y)$$

Eq. 12.13

$$PVC = \sum_y ECI(y) \times DF(y)$$

Eq. 12.14

Where:

OCS(*y*)= total annual operating cost savings realized in the OSSDAP in year *y*, relative to the base case (2012\$),

ECI(*y*)= total annual equipment cost increase for shipments in year *y*, relative to the base case (2012\$), and

DF(*y*)= discount factor in each year (defined in section 12.3.2.3).

DOE calculated PVC and PVS for all lamps projected to be shipped from 2017 to 2046, the duration of the shipments analysis period. To account for all energy savings that accrue for lamps shipped near the end of the analysis period, as well as any changes in lamp disposal costs, it was necessary to consider energy consumption and cash flows through 2080 to include the full lifetime off all stock shipped during the analysis period. The contributions to PVC and PVS for each year were discounted to 2013. The following sections describe how DOE derives the variables in Eq. 12.13 and Eq. 12.14

12.3.2 Net Present Value Inputs

The inputs to DOE's calculation of the NPV of costs and savings for the nation are:

- the total annual installed cost (TIC) of equipment shipped in each year of the analysis, in the base case and the standards cases,
- the total annual operating cost (TOC) for the OSSDAP in the base case and the standards cases, and
- the discount factor (DF).

The computation of these inputs from the outputs of upstream analyses is detailed in the following sections.

12.3.2.1 Total Annual Installed Cost Increases

DOE calculated the total national equipment cost increase in each year of using more efficient lamps in the standards cases relative to the base case as the difference between the TIC in the standards case and the base case:

$$ECI(y) = TIC_{std}(y) - TIC_{base}(y) \quad \text{Eq. 12.15}$$

Where:

$ECI(y)$ = the national equipment cost increase in the standards case, relative to the base case, in year y ,

$TIC_{std}(y)$ = the total installed cost of equipment shipped in year y in the standards case (2012\$), and

$TIC_{base}(y)$ = the total installed cost of equipment shipped in year y in the base case (2012\$).

For IRLs, the per-unit installed cost includes the lamp first cost and the lamp installation cost. Thus, the TIC is given by the following equation:

$$TIC_{IRL}(y) = \sum_l s_{IRL,l}(y) \times (p_{IRL,l}(y) + I_{IRL}) \quad \text{Eq. 12.16}$$

Where:

$s_{IRL,l}(y)$ = total shipments of IRL option l in year y (number of units),
 $p_{IRL,l}(y)$ = purchase price of IRL option l in year y , including corrections for learning (2011\$/unit), and
 I_{IRL} = installation cost of IRLs (2012\$/unit).

The computation of the variables in Eq. 12.16 is described in chapter 11 of this TSD. The summation is over all IRL lamp options considered in that chapter.

For GSFLs, the total annual installed cost is calculated by summing over the ballast types:

$$TIC_{GSFL}(y) = \sum_B TIC_{GSFL,B}(y) \quad \text{Eq. 12.17}$$

Where:

$TIC_{GSFL,B}(y)$ = total installed cost for lamps and ballasts shipped for installation in lamp-and-ballast systems utilizing ballast option B , in year y (2012\$).

Eq. 12.17 is used to compute either the TIC for all GSFLs, by summing over all ballast options, or to compute the TIC for GSFLs of a particular lamp type, by summing only over the ballast options within that type.

The NIA accounts for lamp and lamp-related costs at the time they are incurred. Therefore, for GSFLs installed on new ballasts, DOE accounts for the first cost of the lamp, the first cost of the ballast, and the ballast installation cost. For ballast replacements, DOE also accounts for the disposal cost of the lamps that are retired with the ballast^e. For lamp replacements on existing ballasts, DOE accounts for the disposal cost of the retired lamp and the first cost of the new lamp. For each ballast option B , the total annual installed cost is described by the following equation:

$$TIC_B(y) = s_B(y) \times (p_B(y) + I_B) + s_{GSFL,B}(y) \times \left(\sum_l [MS_{l,B}(y) \times p_{GSFL,l,B}(y)] + I_{GSFL,B} \right) + DC_{GSFL,B}(y) \quad \text{Eq. 12.18}$$

Where:

$s_B(y)$ = total shipments of ballasts option B in year y (number of units),
 $p_B(y)$ = purchase price of ballasts option B in year y , including corrections for learning (2012\$/unit),

^e As discussed in chapter 11, DOE assumes that old lamps are disposed of upon ballast replacement so that all new ballasts are coupled with new lamps when they are installed.

$I_{Bj}(y)$ = installation cost of ballast option B (2012\$/unit),
 $s_{GSFL,B}(y)$ = shipments of GSFLs coupled to ballasts option B in year y (number of units),
 $MS_{l,B}(y)$ = market share of lamp option l among new lamps coupled to ballasts option B in year y ,
 $p_{GSFL,l,B}(y)$ = purchase price of lamp option l in year y , including corrections for learning and any rare earth oxide price impacts (2012\$/unit),
 $I_{GSFL,B}$ = installation cost of GSFLs coupled to ballasts option B (2012\$/unit), and
 $DC_{GSFL,B}$ = disposal cost of GSFLs coupled to ballasts option B (2012\$/unit).

The total installed costs are calculated for the years 2017 to 2080, with all shipments assumed to be zero after 2046 (the final year of the analysis period) and only disposal costs accruing in the later years, for retiring lamps that were shipped between 2017 and 2046. The calculation of the variables in Eq. 12.18 is described in chapter 11 of this TSD, except for the disposal costs, the computation of which is detailed in the following.

The annual disposal cost for lamps coupled to ballast option B , $DC_{GSFL,B}(y)$, is calculated using the following equation:

$$DC_{GSFL,B}(y) = ADC_{GSFL,B} \times \sum_{v=y_0}^{y-1} [s_{GSFL,B}(v) \times P_{LBR,B}(y-v)]$$

Eq. 12.19

Where:

$ADC_{GSFL,B}$ = average disposal cost for retired GSFLs installed on ballasts option B , which is taken to be 30 percent of the individual lamp disposal cost, since DOE assumes that 30 percent of consumers pay this cost, as discussed in chapter 8 of this TSD (2012\$/unit),

$s_{GSFL,B}(v)$ = shipments of GSFLs installed on ballasts option B , in vintage year v (number of units), and

$P_{LBR,B}(y-v)$ = the probability that a lamp or its ballast is retired in year $y-v$ of the lamp's life, for lamp-and-ballast systems incorporating ballast option B , as presented in chapter 11 of this TSD.

To establish the per-unit installed cost, DOE based installation costs on nationally representative values for each lamp design or each lamp-and-ballast system. See chapter 8 of this TSD for further descriptions of installation and disposal costs, and chapter 7 of this TSD and appendix 7A of this TSD for lamp and ballast prices.

12.3.2.2 Total Annual Operating Cost Savings

DOE expresses savings in operating costs as cost reductions associated with the lower energy consumption of products shipped in the standards case compared to the base case. DOE calculated the total annual operating cost savings as the difference between the TOC in the standards case and the base case. As for the computation of the NES, the TOC need not be computed for the total stock $\$,$ but only for the OSSDAP, $\$'$:

$$OCS(y) = TOC'_{base}(y) - TOC'_{std}(y)$$

Eq. 12.20

Where:

$OCS(y)$ = the total operating cost saving of OSSDAP in year y (2012\$),

$TOC'_{base}(y)$ = the total operating cost of the OSSDAP in year y in the base case (2012\$),
and

$TOC'_{std}(y)$ = the total operating cost of the OSSDAP in year y in the standards case (2012\$).

The only component of annual operating cost for lamps is the cost of electricity consumption. As described in the life-cycle cost (LCC) and payback period (PBP) analysis (chapter 8 of this TSD), DOE calculated the total annual operating costs based on national average electricity prices. DOE used the reference-case, sector-specific electricity price projections from *AEO2013* to establish all electricity prices. As *AEO2013* only projects prices through 2040, electricity prices in later years were extrapolated based on the 2030 through 2040 sector-specific trends, up through 2060, after which prices were assumed to remain constant. As discussed in chapter 11 of this TSD, when jointly analyzing lamps in the commercial and industrial sectors, DOE used a weighted average of the commercial and industrial electricity price projections, based on the fraction of the total stock that is assumed to be installed in the industrial sector for each ballast type.

DOE calculated annual TOC for IRLs by summing over the operating costs of all lamp options in the OSSDAP, according to the following expression:

$$TOC'_{IRL}(y) = p_E(y) \times \sum_l [S'_{l,IRL}(y) \times UEC_{l,IRL}(y)]$$

Eq. 12.21

Where:

$p_E(y)$ = the price of electricity, in year y , as forecasted in the *AEO2013* reference scenario (2012\$/kWh),

$S'_{l,IRL}(y)$ = the OSSDAP of IRL type l in year y (number of units), and

$UEC_{l,IRL}(y)$ = the average unit energy consumption of IRL type l in year y , as computed using Eq. 12.11(kWh/unit).

For IRLs, DOE uses the forecast of national-average commercial and residential electricity prices for its analysis in the commercial and residential sectors, respectively.

To compute the annual TOC for GSFLs, DOE summed the operating costs of lamps installed on all of the ballast options it considered in the shipments analysis:

$$TOC'_{GSFL}(y) = \sum_B TOC'_{B,GSFL}(y)$$

Eq. 12.22

Where:

$TOC'_{B,GSFL}(y)$ = the annual total operating costs of lamps installed on ballasts option B in year y (2012\$).

The TOC for lamps installed on a particular ballast option is given by a sum over the OSSDAP fractions of the lamp options that can be installed on that ballast:

$$TOC'_{B,GSFL}(y) = S'_{B,GSFL}(y) \times p_E(y) \times \sum_l [\phi_{l,B}(y) \times UEC_{l,B,GSFL}(y)]$$

Eq. 12.23

Where:

$S'_{B,GSFL}(y)$ = the OSSDAP of GSFLs installed on ballasts option B in year y (number of units),

$p_E(y)$ = the price of electricity, in year y , as forecasted in the *AEO2013* reference scenario (2012\$/kWh),

$\phi_{l,B}(y)$ = the fraction of the OSSDAP of all lamps installed on ballasts option B that are lamp option l , and

$UEC_{l,B,GSFL}(y)$ = the annual unit energy consumption of lamp option l installed on ballast type B , as computed using Eq. 12.11 (kWh/unit).

For 4-foot medium bipin (MBP) lamps installed on residential ballasts, DOE used the projection of national average residential electricity prices. For all other GSFLs in the stock, DOE used a weighted average of the electricity price projections in the commercial and industrial sectors, as described in chapter 11 of this TSD.

To understand the importance of uncertainty in these projections, DOE performed sensitivity analyses using the high- and low-economic growth scenarios from *AEO2013* to establish electricity prices. Figure 12.3.1 shows annual electricity price projections used as inputs for the high-, reference-, and low-economic growth scenarios, for all sectors. Note that there is not a consistent relationship over time between the economic growth scenario and its impact on electricity prices. For example, in the early years of the analysis period, the low-economic growth scenario in the residential sector results in higher electricity prices than the high growth scenario. The opposite is true in later years.

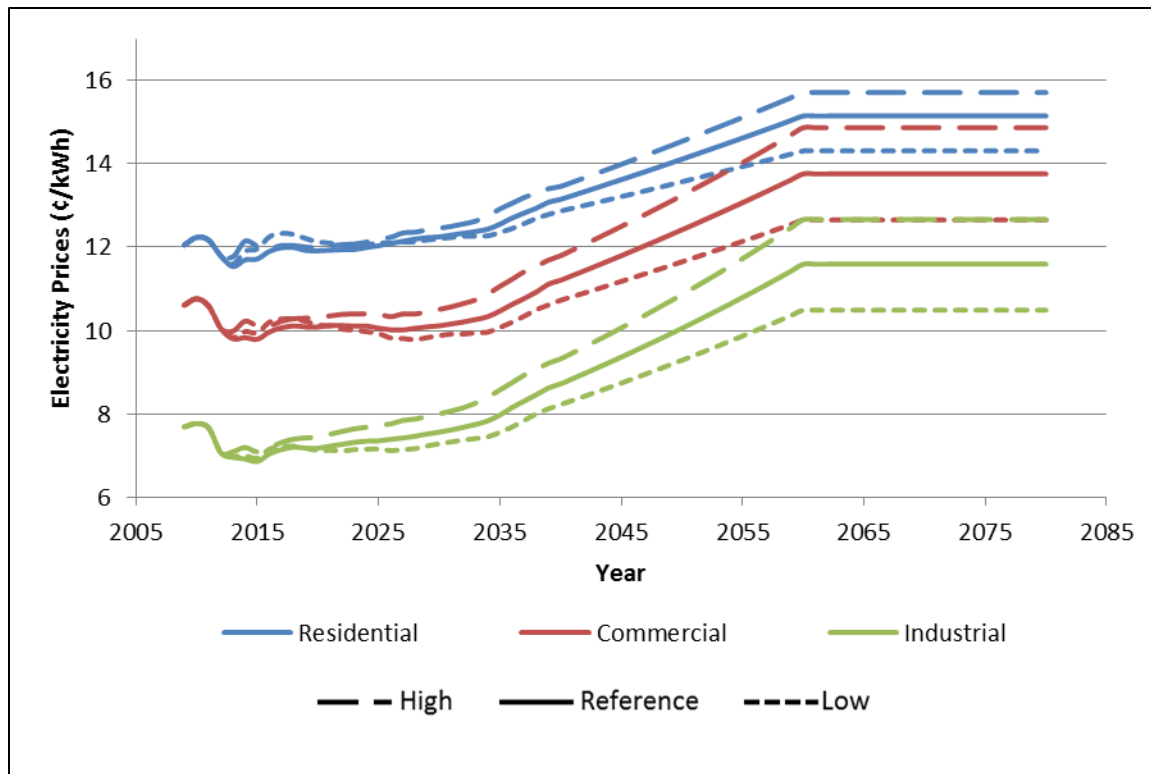


Figure 12.3.1 Annual Electricity Prices by Sector (2012\$)

As discussed in section 12.2.3.5, DOE has included in this analysis scenarios that include various assumptions about rebound to adjust its estimates of NES. In principle, the rebound effect also affects the energy costs to consumers in the standards case. However, the take-back in energy consumption associated with the rebound effect provides consumers with increased value (*e.g.*, improved lighting quality). As described in the 2012 residential furnace fan TSD⁴, DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA based on rebound.

12.3.2.3 Discount Factor

DOE multiplies monetary values in future years by a discount factor to determine the present value. The DF is described by the equation:

$$DF = \frac{1}{(1 + r)^{(y - y_p)}}$$

Eq. 12.24

Where:

r = discount rate,

y = year of the monetary value, and

y_p = year for which the present value is being determined.

DOE estimates NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: *Identifying and Measuring Benefits and Costs*. DOE defines the present year as 2013.

12.4 RESULTS

This section summarizes the NES and NPV modeling results for the five trial standard levels and the results of the alternative scenarios used to determine sensitivities and the impacts of key variables.

12.4.1 National Energy Savings Results

Table 12.4.1 and Table 12.4.2 present DOE's best estimates of the cumulative primary (at the power plant) NES and full-fuel-cycle NES respectively, relative to the base case for GSFLs, for all lamp types and TSLs. For GSFLs, TSL 5 offers the largest energy savings. Table 12.4.3 presents the primary and full-fuel-cycle NES for IRLs for the reference case. As is evident from Table 12.4.1-Table 12.4.3, GSFLs offer significantly larger potential for energy savings than IRLs; this is expected, since the base case electricity consumption for GSFLs is much greater than the IRL electricity consumption and, therefore, has a higher potential for energy savings.

Table 12.4.1 Cumulative Primary (Power Sector Consumption) NES for GSFLs for all TSLs, Reference Scenario

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	Quads				
4-foot MBP	0.00	-0.11	1.41	9.5	7.7
8-foot Slimline	0.00	0.13	-0.08	-0.68	-0.19
8-foot RDC HO	0.00	0.02	0.00	0.00	0.02
4-foot T5, MiniBP SO	0.01	-0.01	-0.66	-6.1	-4.3
4-foot T5, MiniBP, HO	0.19	0.17	0.19	0.20	0.18
2-foot U-shaped*	0.00	0.00	0.00	0.00	0.00
Total GSFL	0.20	0.20	0.86	2.9	3.3

* For all TSLs, the energy savings for 2-foot U-shaped lamps are several orders of magnitude too small to be shown at the level of precision presented here.

Table 12.4.2 Cumulative FFC NES for GSFLs for all TSLs, Reference Scenario

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	Quads				
4-foot MBP	0.00	-0.12	1.5	9.9	8.0
8-foot Slimline	0.00	0.13	-0.09	-0.71	-0.20
8-foot RDC HO	0.00	0.02	0.00	0.00	0.02
4-foot T5, MiniBP SO	0.01	-0.01	-0.69	-6.3	-4.5
4-foot T5, MiniBP, HO	0.19	0.18	0.20	0.20	0.18
2-foot U-shaped*	0.00	0.00	0.00	0.00	0.00
Total GSFL	0.21	0.21	0.89	3.0	3.5

* For all TSLs, the energy savings for 2-foot U-shaped lamps are several orders of magnitude too small to be shown at the level of precision presented here.

Table 12.4.3 Cumulative NES for IRL Standard, Reference Scenario

	Trial Standard Level
	1
	Quads
Primary Energy (Power Sector Consumption)	0.013
FFC Energy	0.013

As discussed in chapter 11 of this TSD, the shipments analysis implements a consumer choice model, which allows for the possibility that consumers will switch between lamp types in response to economic signals. In the base case, the model projects shifts between lamp types that proceed relatively slowly. However, if a potential standard causes a substantial increase in the first costs associated with one lamp type relative to another, the shipments model tends to project a more rapid shift in market share to the newly more cost-effective lamp type. Therefore, a portion of the NES and NPV of each TSL derives from consumers' switching between lamp types in response to the new standard. In this analysis, DOE refers to this phenomenon as *standards-induced product class switching*.

As discussed in chapter 11 of this TSD, for some TSLs, this switching yields an increase in shipments for certain GSFL product classes, at the expense of reduced shipments in other product classes. Because of these market shifts, the NES values for a single product class, considered in isolation, can be misleading. In particular, a negative NES for a single product class does not imply a net increase in energy consumption under standards. Instead, a negative NES in a single product class can occur simply because more lamps from that product class are

shipped and operated during the analysis period in the standards case than in the base case. This negative value will be offset by a positive NES from foregone shipments in the original product class. We discuss this effect in more detail in the context of NPV in Section 12.4.2.

Thus, when standards-induced product class switching is included in the shipments model, the NES for a single product class gives an incomplete picture of the total energy savings at each TSL. DOE therefore considered only the total NES values, summed over all product classes, when assessing the impact of each TSL on national energy consumption. The per-product-class NES values are presented in Tables Table 12.4.1 and Table 12.4.2 for informational purposes only. The impact of standards-induced product class switching on total NES is discussed in section 12.4.3.4.

12.4.2 Net Present Value Results

Table 12.4.4 and Table 12.4.5 show the cumulative NPV at 3-percent and 7-percent discount, respectively, for GSFLs, for all lamp types and TSLs in the reference scenario. For GSFLs, TSL 4 has the highest NPV at both a 3 and a 7-percent discount rate, very slightly exceeding the NPV of TSL5. All other TSLs have significantly lower NPV than these two. Table 12.4.6 presents the cumulative NPV at 3-percent and 7-percent discount for IRL in the reference scenario.

Table 12.4.4 Cumulative Net Present Value for GSFL, by Lamp Type for Reference Case at 3% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	-0.98	7.7	64	48
8-foot Slimline	0.00	1.06	-0.76	-6.1	-2.3
8-foot RDC HO	-0.06	0.06	-0.06	-0.06	0.06
4-foot T5, MiniBP SO	-0.15	-0.32	-5.8	-51	-39
4-foot T5, MiniBP, HO	-0.28	-0.43	-0.28	-0.23	-0.39
2-foot U-shaped	0.00	-0.03	0.22	1.73	1.31
Total GSFL	-0.49	-0.63	1.0	8.1	8.1

Table 12.4.5 Cumulative Net Present Value for GSFL, by Lamp Type for Reference Case at 7% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	-0.61	4.2	35	26
8-foot Slimline	0.00	0.66	-0.48	-3.7	-1.5
8-foot RDC HO	-0.05	0.03	-0.05	-0.05	0.03
4-foot T5, MiniBP SO	-0.10	-0.21	-3.30	-28	-22
4-foot T5, MiniBP, HO	-0.24	-0.34	-0.24	-0.22	-0.32
2-foot U-shaped	0.00	-0.02	0.11	0.87	0.65
Total GSFL	-0.39	-0.48	0.23	3.2	3.1

Table 12.4.6 Cumulative Net Present Value for IRL

	TSL 1
	billion 2012\$
3% discount rate	0.28
7% discount rate	0.18

As with the NES numbers presented in Section 12.4.1 of this TSD, the NPV numbers for GSFL are strongly affected by standards-induced product class switching. Because of this, the NPV results for individual product classes can be misleading. In particular, a negative NPV for a single product class therefore does not imply a reduction in consumer benefit. If a significant fraction of consumers switches from one product class to another in the standards case, then the NPV of the second product class will be negative simply because more lamps are shipped and operated in that product class in the standards case. This negative value will be offset by a positive NPV from foregone shipments in the original product class.

For example, the negative NPVs for T5 SO lamps at TSLs 3, 4, and 5, seen in Tables Table 12.4.4 and Table 12.4.5 occurs largely because there is a significant market-share shift away from 4-ft MBP T8s and toward SO T5s in each standards case. The negative contribution to NPV from increased shipments of T5s is offset by a positive contribution to the NPV from reduced shipments of 4-ft MBP T8s. Summing the NPV of the two product classes yields a total NPV that is positive.

Thus, when standards-induced product class switching is included in the shipments model, the NPV for a single product class gives an incomplete picture of the total consumer benefit at each TSL. DOE therefore considered only the total NPV results, summed over all product classes when assessing the impact of each TSL on consumer benefit. Similar arguments apply to the equipment cost increases and energy cost savings presented on a per-product-class basis in the remainder of this section (Tables Table 12.4.7, Table 12.4.8, Table 12.4.10, and Table 12.4.11). Per-product-class NPV and consumer cost results are presented in this section for informational purposes only. The impact of standards-induced product class switching on total NPV is discussed in section 12.4.3.4.

Table 12.4.7 and Table 12.4.8 show the estimated cumulative equipment cost increase at 3-percent and 7-percent discount, respectively, for products shipped during the analysis period, for all lamp types and TSLs, for GSFLs. Table 12.4.9 shows the estimated cumulative equipment cost increase for IRL at 3-percent and 7-percent. The negative equipment cost increase for IRL occurs because the lamp options at EL1 both have significantly longer lifetimes than the Baseline lamp; hence, consumers purchase significantly fewer IRLs overall in the standards case relative to the base case.

Table 12.4.7 Cumulative Equipment Cost Increase for GSFL for Reference Case at 3% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	0.28	0.62	-8.8	-3.8
8-foot Slimline	0.00	-0.27	0.26	2.06	1.1
8-foot RDC HO	0.06	0.05	0.06	0.06	0.05
4-foot T5, MiniBP SO	0.23	0.28	2.0	16	14
4-foot T5, MiniBP, HO	1.4	1.5	1.4	1.4	1.5
2-foot U-shaped	0.00	0.00	0.12	0.52	0.52
Total GSFL	1.7	1.8	4.5	11	13

Table 12.4.8 Cumulative Equipment Cost Increase for GSFL for Reference Case at 7% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	0.20	0.43	-5.2	-2.2
8-foot Slimline	0.00	-0.19	0.18	1.4	0.77
8-foot RDC HO	0.05	0.04	0.05	0.05	0.04
4-foot T5, MiniBP SO	0.14	0.18	1.3	10	9.0
4-foot T5, MiniBP, HO	0.90	0.93	0.90	0.90	0.92
2-foot U-shaped	0.00	0.00	0.08	0.33	0.33
Total GSFL	1.1	1.2	2.9	7.6	8.8

Table 12.4.9 Cumulative Equipment Cost Increase for IRL

	TSL 1
	billion 2012\$
3% discount rate	-0.17
7% discount rate	-0.11

Table 12.4.10 and Table 12.4.11 show the cumulative energy cost savings for GSFL at 3-percent and 7-percent discount, respectively, for all lamp types and TSLs in the reference scenario. For GSFL the largest energy cost savings occurs at TSL 5 at both a 3 and 7-percent discount rate. Table 12.4.12 show the cumulative energy cost savings for IRL at 3-percent and 7-percent discount.

Table 12.4.10 Cumulative Energy Cost Savings for GSFL for Reference Case at 3% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	-0.70	8.3	55	45
8-foot Slimline	0.00	0.79	-0.51	-4.1	-1.2
8-foot RDC HO	0.00	0.12	0.00	0.00	0.12
4-foot T5, MiniBP SO	0.08	-0.04	-3.8	-35	-25
4-foot T5, MiniBP, HO	1.1	1.0	1.1	1.2	1.1
2-foot U-shaped	0.00	-0.03	0.34	2.2	1.8
Total GSFL	1.2	1.2	5.5	20	22

Table 12.4.11 Cumulative Energy Cost Savings for GSFLs for Reference Case at 7% discount rate

Lamp Type	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
	billion 2012\$				
4-foot MBP	0.00	-0.41	4.6	29	24
8-foot Slimline	0.00	0.47	-0.30	-2.32	-0.69
8-foot RDC HO	0.00	0.07	0.00	0.00	0.07
4-foot T5, MiniBP SO	0.04	-0.03	-2.0	-18	-13
4-foot T5, MiniBP, HO	0.66	0.59	0.66	0.67	0.60
2-foot U-shaped	0.00	-0.02	0.19	1.2	0.99
Total GSFL	0.70	0.68	3.1	11	12

Table 12.4.12 Cumulative Energy Cost Savings for IRL

	TSL 1
	billion 2012\$
3% discount rate	0.10
7% discount rate	0.072

12.4.3 Alternative Analyses Results

12.4.3.1 Overview

To gauge the importance of various assumptions and uncertainties in the NIA, DOE carried out the NIA for several alternative scenarios and compared the NES and NPV results to the reference scenario. Inputs that affect the NIA only, and not the shipments, are listed in Table 12.4.13. AEO scenarios affect the electricity prices^f used to calculate the energy cost savings as

^f In principle, the shipments analysis should also use these electricity forecasts to project shipments in these scenarios, because the different electricity prices will impact the consumer choice model. However, DOE performed a sensitivity analysis using the different AEO forecasts in the shipments model and found negligible impact on the projected shipments. To simplify the model, DOE, therefore, chose to use only the reference AEO scenario in the shipments analysis, regardless of the electricity price forecast selected for the NIA.

described in section 12.3.2.2. The rebound scenarios, described in section 12.2.3.5 and appendix 12C, determine the effects on NES of different rebound rate assumptions.

Table 12.4.13 Alternative NIA Scenarios

	Scenario
AEO Economic Growth	High
	Low
Rebound Scenario*	Framework**
	High†

* Reference rebound rates are as follows: Commercial 0% and Residential 0%

**Framework rebound rates are as follows: Commercial 1% and Residential 8.5%

†High rebound rates are as follows: Commercial 15%, Residential 15%.

Table 12.4.14 lists the alternative scenarios that affect the shipments projections and therefore also the NIA; the details of these alternative scenarios and their effects on shipments are discussed in chapter 11 of this TSD. DOE considered two types of alternative scenarios: sensitivity analyses explore the effect of uncertainties in input variables, and impact analyses explore the effect of certain assumptions about future market conditions.

Table 12.4.14 Alternative and Best Estimate Shipments Scenarios

Scenarios	Scenario Name	Products Applied	Description
Best Estimate	Reference	GSFL/IRL	Reference values for REO prices, controls adoption and LED incursion. Includes modeled baseline lamps and allows for standards induced product class switching
Sensitivity Analyses	High REO Price	GSFL	High REO prices as described in chapter 11, all other parameters same as Reference scenario
	Market Minimum Efficacy	GSFL	Does not include modeled baseline lamps, all other parameters same as Reference scenario
	IRL Short Life	IRL	Assumes EL 1 is met with a short-lived lamp as described in chapter 11, all other parameters same as Reference scenario
	High Xe Price	IRL	High xenon prices, all other parameters same as Reference scenario
Impact Analyses	Fixed Controls	GSFL/IRL	Holds controls adoption fixed at current rates as described in chapter 11, all other parameters same as Reference scenario
	No Standards-Induced PC switching	GSFL	Does not allow standards-induced switching between product classes, as described in chapter 11; all other parameters same as Reference scenario
	No LEDs	GSFL/IRL	LED market share held at 2013 levels for entire analysis period as described in chapter 11, all other parameters same as for Reference scenario
	9-Year Analysis	GSFL/IRL	Analysis period of 2017-2025 as described in chapter 11, all parameters same as for Reference Scenario

For GSFL the sensitivity analyses consider a scenario with high rare earth oxide (REO) prices and a scenario that excludes modeled baseline lamps for 8-foot HO, T5 SO and T5 HO lamp types. For IRL the sensitivity analyses consider a scenario with shorter-lived lamps that meet EL 1 and a scenario with high xenon prices. Relevant details of these scenarios and results are presented in sections 12.4.3.2 and 12.4.3.3.

Impact analyses that affect both GSFL and IRL include a scenario with a fixed incursion of lighting control systems, as well as a scenario in which no further LED incursion occurs into either the GSFL or the IRL markets. DOE also performed an analysis using a 9-year analysis period, instead of the standard 30-year analysis period. For GSFL only, the impacts of standards-induced product class switching are also assessed by considering a scenario in which annual

GSFL shipments for each lamp type are held fixed at their baseline values. Again, DOE does not consider the impact-analysis scenarios to be probable market outcomes; results are included in the alternative scenarios for informational purposes only. Relevant details of these scenarios and results are presented in section 12.4.3.4.

12.4.3.2 Sensitivity Analyses: National Energy Savings Results

Table 12.4.15 presents the power plant and full fuel cycle cumulative NES for the sensitivity analyses that affect GSFL. Table 12.4.16 presents the power plant and full fuel cycle NES for the sensitivity analyses that affect IRL. In each TSL, the scenario result for the sensitivity analyses should be compared to the reference scenario to determine the impact.

Table 12.4.15 Cumulative NES, Sensitivity Analyses, GSFL

GSFL		TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Scenarios		quads				
Reference	Power Plant	0.20	0.20	0.86	2.9	3.3
	Full-Fuel-Cycle	0.21	0.21	0.89	3.0	3.5
Framework Rebound	Power Plant	0.20	0.20	0.85	2.9	3.3
	Full-Fuel-Cycle	0.21	0.20	0.88	3.0	3.4
High Rebound	Power Plant	0.17	0.17	0.73	2.5	2.8
	Full-Fuel-Cycle	0.18	0.17	0.76	2.6	2.9
High RE Price	Power Plant	0.23	0.22	0.91	3.0	3.5
	Full-Fuel-Cycle	0.24	0.23	0.95	3.2	3.6
Market Minimum Efficacy	Power Plant	0.0	0.0	0.66	2.7	3.1
	Full-Fuel-Cycle	0.0	0.0	0.68	2.8	3.2

Table 12.4.16 Cumulative NES, Sensitivity Analyses, IRL

IRL		TSL 1
Scenarios		quads
Reference	Power Plant	0.012
	Full-Fuel-Cycle	0.013
Framework Rebound	Power Plant	0.011
	Full-Fuel-Cycle	0.012
High Rebound	Power Plant	0.011
	Full-Fuel-Cycle	0.011
IRL Short Life	Power Plant	0.011
	Full-Fuel-Cycle	0.012
High Xe Price	Power Plant	0.010
	Full-Fuel-Cycle	0.010

In general, the different sensitivity-analysis scenarios do little to change the overall pattern of NES results: positive NES values remain positive, and the maximum NES for GSFL remains at TSL 5. The main results are summarized below:

- For IRL and GSFL, the impact on the NES of the different rebound assumptions is straightforward: there is a fractional reduction in energy savings equal to the rebound rate in each sector. Since GSFLs are used mostly in the commercial and industrial sector and IRLs are used mostly in the residential sector,⁵ the overall impact of the framework rebound assumptions is greater for IRLs than for GSFLs; GSFLs see a reduction in NES of approximately 1 percent, while the reduction in NES for IRLs is closer to the residential rate of 8.5 percent. In the case of high rebound assumptions, the NES reduction is 15 percent for both products.
- In general, the effects of the sensitivity analyses are small for IRL, less than 10 percent for all scenarios except high xenon price. The high xenon scenario has a full fuel cycle NES approximately 20 percent lower than the reference scenario
- For GSFL, the assumption of increased REO prices increased the NES between 3-and 15-percent compared to the reference scenario, the largest difference occurring in TSL 1.
- The Market Minimum Efficacy scenario for GSFL eliminated the NES for TSL 1 and TSL 2. For TSL 1 this is expected because the base case in the Market Minimum Efficiency scenario has the same ELs as TSL 1 in the reference scenario resulting in zero energy savings between the two. For TSL 2 the ELs differ from TSL 1 only in the two 8-foot lamp types which account for only a small fraction of the overall energy use, resulting in a NES differential that rounds to zero. For remaining TSLs the change in

NES is more modest, approximately 20 percent lower for TSL 3, and less than 10 percent lower for TSL 4 and TSL 5, compared to the reference scenario.

12.4.3.3 Sensitivity Analyses: Net Present Value Results

This section presents the alternative analyses that affect the NPV. Table 12.4.17 and Table 12.4.18 present the cumulative NPV at 3 and 7-percent discount rates for GSFL and IRL respectively.

Table 12.4.17 Cumulative NPV for Alternative Scenarios, GSFL

GSFL		TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Scenarios	Discount Rate	Billion 2012\$				
Reference	3%	-0.49	-0.63	1.0	8.1	8.1
	7%	-0.39	-0.48	0.23	3.2	3.1
AEO High	3%	-0.45	-0.59	1.3	8.9	8.9
	7%	-0.36	-0.45	0.34	3.6	3.6
AEO Low	3%	-0.52	-0.66	0.92	7.7	7.6
	7%	-0.40	-0.49	0.18	3.0	2.9
High RE Price	3%	-0.55	-0.77	1.3	8.9	8.5
	7%	-0.44	-0.56	0.35	3.5	3.3
Market Minimum Efficacy	3%	0.0	-0.14	1.5	8.6	8.6
	7%	0.0	-0.09	0.62	3.6	3.5

Table 12.4.18 Cumulative NPV for Alternative Scenarios, IRL

IRL		TSL 1
Scenarios	Discount Rate	Billion 2012\$
Reference	3%	0.28
	7%	0.18
AEO High	3%	0.28
	7%	0.18
AEO Low	3%	0.28
	7%	0.18
IRL Short Life	3%	0.11
	7%	0.06
High Xe Price	3%	0.28
	7%	0.18

In general, the different sensitivity-analysis scenarios do little to change the overall pattern of NPV results: positive NPVs remain positive, negative NPVs remain negative, and the maximum NPV remains at TSL 4. The main results are summarized below.

- In the high economic growth scenario the NPV is increased for GSFL in all TSLs, compared to the reference scenario, and is unchanged for IRL to the reported precision. Conversely, in the low economic growth scenario the NPV is lower for GSFLs in all TSLs. Again for IRL the results are unchanged to the reported precision.
- In the high REO price scenario the NPV is modestly higher in absolute terms compared to the reference scenario. The fractional increases, however, range from 13 to 50 percent higher for TSLs 1, 2, and 3 where the NPV in the reference scenario was small.
- The high xenon price scenario does not affect the NPV of IRLs to the reported precision.
- In the IRL short-life scenario the NPV is approximately 70-percent lower than the reference case, due to the increased equipment costs associated with more frequent lamp replacement.

12.4.3.4 Impact Analyses: Results

As discussed previously, DOE performed several alternative analyses to gauge the impact of certain assumptions about future market conditions. The results summarized in this section give an estimate of the importance of these assumptions to the final NIA results. Although the differences from the reference case can be very significant, DOE does not consider the impact-analysis scenarios to represent likely market outcomes. The results in this section are therefore presented for informational purposes only and should not be construed as uncertainty estimates.

The impacts of the LED and controls assumptions are can be summarized briefly as follows. Holding controls fixed at their current levels has a small impact on all TSLs except TSL 4 where the NES and NPV are lower by approximately 30 percent and 50 percent respectively, compared to the reference case. Holding LEDs at their current levels more than doubles the NES and NPV for all TSLs compared to the reference case. The impacts of considering a 9-year analysis period and of product class switching are discussed in more depth below.

The results using a 9-year analysis period, rather than DOE's standard 30-year analysis period are summarized in Table 12.4.19 and Table 12.4.20 for GSFL and IRL, respectively. As shown, more than one-third of the NES and NPV values from the reference analysis are achieved in the first nine years of the analysis period. This is because the incursion of LEDs into the market leads to a significantly reduced impact of standards in later years.

Table 12.4.19 GSFL 9-Year Analysis, Cumulative NPV and NES

GSFL		TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
Scenarios		quads				
NES	Power Plant	0.10	0.10	0.42	1.3	1.5
	Full Fuel Cycle	0.10	0.10	0.44	1.4	1.5
		Billion 2012\$				
NPV	3% discount	-0.29	-0.39	0.37	2.5	2.7
	7% discount	-0.26	-0.33	0.04	1.1	1.1

Table 12.4.20 IRL 9-Year Analysis, Cumulative NPV and NES

IRL		TSL 1
Scenarios		
NES	Power Plant	0.008
	Full Fuel Cycle	0.008
		Billion 2012\$
NPV	3%	0.18
	7%	0.13

As mentioned in section 12.4.1, and discussed in depth in chapter 11 of this TSD, the shipments analysis is based on a consumer choice model that explicitly considers the possibility of standards-induced product class switching. Most notably, the standards cases for TSLs 3, 4, and 5 show that a fraction of the consumers who purchase 4-foot MBP lamps in the base case will instead choose either to utilize 8-foot slimline or to T5 SO systems under standards. Such

standards-induced product-class switching can have a significant effect on the national impacts of a proposed standard; this section summarizes the role that product-class switching plays in determining the NIA results.

As discussed in section 12.4.3 and in chapter 11 of this TSD, DOE has considered an alternative scenario for this NOPR TSD in which the shipments projections for each of the standards cases were assumed to be identical to the base case shipments projections. In other words, any shifts in market share for the various lamp types that are projected to occur in the absence of standards remain in the model, but any further shifts that may be induced by standards are excluded from the model.

Table 12.4.21 presents NIA results^g for GSFLs under each TSL, in both the reference scenario and the alternative scenario without standards-induced product class switching, as well as the difference in national impacts between the two scenarios.

^g For the sake of brevity, economic results are shown only for the 7% discount rate. The impacts for the 3% discount rate are qualitatively similar.

Table 12.4.21 Impacts from Standards-induced Product Class Switching on the NIA results for GSFLs^g

	Total, reference case	Total, without standards- induced PC switching	Difference arising from standards- induced PC switching
NES (FFC)			
TSL1	0.21	0.21	0.00
TSL2	0.21	0.22	-0.02
TSL3	0.89	0.75	0.14
TSL4	3.03	2.15	0.88
TSL5	3.46	2.37	1.09
NPV (7% DR)			
TSL1	-0.39	-0.39	0.00
TSL2	-0.48	-0.46	-0.02
TSL3	0.23	-0.32	0.55
TSL4	3.18	-1.77	4.95
TSL5	3.13	-1.58	4.71
Operating Cost Savings (7% DR)			
TSL1	0.70	0.70	0.00
TSL2	0.68	0.75	-0.07
TSL3	3.14	2.65	0.49
TSL4	10.76	7.58	3.18
TSL5	11.97	8.27	3.70
Added Equipment Costs (7% DR)			
TSL1	1.09	1.09	0.00
TSL2	1.16	1.20	-0.05
TSL3	2.91	2.96	-0.06
TSL4	7.58	9.36	-1.77
TSL5	8.84	9.85	-1.01

The standards-induced product class switching has minimal impact on the NES for TSLs 1 and 2, but it is responsible for a significant fraction of the NES for TSLs 3, 4, and 5. The strong impact on NES may not be what is intuitively expected: as presented in chapter 8 of this TSD, there is little or no difference in energy consumption between a full-wattage 4-foot MBP lamp and a full-wattage T5 SO lamp when each is coupled to its respective baseline non-dimming ballast. However, the system efficacies of the various lamp-and-ballast systems differ within each lamp type, and, in particular, T5 SO systems that incorporate low ballast-factor or dimming ballasts have higher system efficacy than their 4-foot MBP counterparts. The shipments model only allows product-class switching for consumers undertaking renovations, retrofits, or new construction; and the model assumes that these consumers will install a reduced density of lamps, and use proportionally less energy, when they install more efficacious systems. Thus, if the market shift consists mainly of consumers switching from less efficacious 4-foot MBP ballast options in the base case to fewer, more efficacious T5 SO ballast options in the standards case, a net energy savings will occur.

The impact of standards-induced product class switching on NPV is also small for TSLs 1 and 2, but it is extremely significant for TSLs 3, 4 and 5: in the absence of standards-induced product class switching the NPV of these three TSLs is negative, whereas it is large and positive in the reference case. This effect on NPV may be more straightforward to understand than the effect on NES. As shown in Table 12.4.21, the increased energy savings in the reference case yields increased operating-cost savings, which contribute positively to the NPV. In addition, standards-induced product class switching significantly reduces the added equipment costs arising from each TSL, which also contributes positively to NPV.

For TSLs 4 and 5, in particular, product class switching diminishes the added equipment costs because those TSLs lead to very large increases in the price of full-wattage 4-foot MBP lamps—from \$5.35/lamp in the base case to \$10.22/lamp for TSLs 4 and 5, as presented in chapter 7 of this TSD. Full wattage T5 SO lamps are relatively less expensive at these TSLs, with a weighted average price of, *e.g.*, \$6.36/lamp and \$7.56/lamp for TSLs 4 and 5, respectively. In the standards cases corresponding to TSLs 4 and 5, then, consumers can reduce their equipment costs by switching away from the 4-foot MBP product class and into the relatively more affordable T5 SO product class. Similar, though less dramatic, price dynamics drive the equipment cost differentials for TSLs 1 and 2. Thus, it appears that standards-induced product-class switching eases the upward pressure that each TSL exerts on the actual equipment costs borne by consumers, substantially boosting overall NPV.

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CHAPTER 13. MANUFACTURER IMPACT ANALYSIS

13.1 INTRODUCTION

In determining whether a standard is economically justified, the U.S. Department of Energy (DOE) is required to consider “the economic impact of the standard on the manufacturers and on the consumers of the products subject to such a standard.” (42 U.S.C. 6312(a)(6)(B)(i)) The law also calls for an assessment of the impact of any lessening of competition as determined in writing by the Attorney General. *Id.* DOE conducted a manufacturer impact analysis (MIA) to estimate the financial impact of amended energy conservation standards on manufacturers of general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs), and assessed the impact of such standards on direct employment and manufacturing capacity.

The MIA has both quantitative and qualitative aspects. The quantitative part of the MIA primarily relies on the Government Regulatory Impact Model (GRIM), an industry cash-flow model adapted for the products in this rulemaking. The GRIM inputs include information on industry cost structure, shipments, and pricing strategies. The GRIM’s key output is the industry net present value (INPV). The model estimates the financial impact of more stringent energy conservation standards for each product by comparing changes in INPV between a base case and the various trial standard levels (TSLs) in the standards case. The qualitative part of the MIA addresses product characteristics, manufacturer characteristics, market and product trends, as well as the impact of standards on subgroups of manufacturers.

13.2 METHODOLOGY

DOE conducted the MIA in three phases. Phase I, “Industry Profile,” consisted of preparing an industry characterization for the GSFL and IRL industries, including data on market share, sales volumes and trends, pricing, employment, and financial structure. In Phase II, “Industry Cash Flow,” DOE used the GRIMs to assess the impacts of amended energy conservation standards on GSFLs and IRLs.

In Phase II, DOE created separate GRIMs for GSFLs and IRLs, as well as separate interview guides for each product to gather information on the potential impacts amended energy conservation standards would have on manufacturers. DOE presented the MIA results for GSFLs and IRLs separately based on a set of considered TSLs. These TSLs are described in section 13.4.5 below.

In Phase III, “Subgroup Impact Analysis,” DOE interviewed manufacturers that account for more than 90 percent of GSFL sales and 80 percent of IRL sales. Interviewees included large and small manufacturers with various market shares and market focuses, providing a representative cross-section of each industry. During interviews, DOE discussed financial topics specific to each manufacturer and obtained each manufacturer’s view of the relevant industry. The interviews provided DOE with valuable information for evaluating the impacts of amended energy conservation standards on manufacturer cash flows, investment requirements, and employment.

13.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE prepared profiles of the GSFL and IRL industries that built upon the market and technology assessment prepared for this rulemaking (see chapter 3 of this notice of proposed rulemaking (NOPR) technical support document (TSD)). Before initiating the detailed impact studies, DOE collected information on the present and past structure and market characteristics of each industry. This information included market share data, unit shipments, manufacturer markups, and cost structures for various manufacturers. The industry profile includes: (1) further detail on the overall market and product characteristics; (2) estimated manufacturer market shares; (3) financial parameters such as net plant, property, and equipment (PPE); selling, general and administrative (SG&A) expenses; cost of goods sold, etc.; and (4) trends in the number of firms, specific lighting markets, and general product characteristics. The industry profile included a top-down cost analysis of GSFL and IRL manufacturers that DOE used to derive preliminary financial inputs for each GRIM (*e.g.*, revenues, depreciation, SG&A, and research and development (R&D) expenses).

DOE also used public information to further calibrate its initial characterization of the GSFL and IRL industries, including Securities and Exchange Commission (SEC) 10-K reports,¹ Standard & Poor's (S&P) stock reports,² and corporate annual reports. DOE supplemented this public information with data released by privately held companies.

13.2.2 Phase II: Industry Cash-Flow Analysis and Interview Guide

Phase II focused on the financial impacts of potential amended energy conservation standards on manufacturers of GSFLs and IRLs. More stringent energy conservation standards can affect manufacturer cash flows in three distinct ways: (1) create a need for increased investment, (2) raise production costs per-unit, and (3) alter revenue due to higher per-unit prices and/or possible changes in sales volumes. To quantify these impacts, DOE used the GRIMs to perform a cash-flow analysis for GSFLs and IRLs. In performing these analyses, DOE used the financial values derived during Phase I and the shipment scenarios used in the national impact analysis (NIA). In Phase II, DOE performed these preliminary industry cash-flow analyses and prepared written guides for manufacturer interviews.

13.2.2.1 Industry Cash-Flow Analysis

The GRIMs use several factors to determine a series of annual cash flows from the announcement year of amended energy conservation standards until several years after the standards' compliance date. These factors include annual expected revenues, costs of sales, SG&A, taxes, and capital expenditures related to the amended standards. Inputs for each GRIM include manufacturing production costs, selling prices, and shipments forecasts developed in other analyses. DOE derived the manufacturing costs from the engineering analysis and information provided by the industry and estimated typical manufacturer markups from public financial reports and interviews with manufacturers. DOE developed alternative markup scenarios for each GRIM based on discussions with manufacturers. DOE's shipments analysis, presented in chapter 11 of this NOPR TSD, provided the basis for the shipment projections in each GRIM. The financial parameters were developed using publicly available manufacturer data and were revised with information submitted confidentially during manufacturer interviews. The

GRIM results are compared to base case projections for the industry. The financial impact of amended energy conservation standards is the difference between the discounted annual cash flows in the base case and in the standards case at each TSL.

13.2.2.2 Interview Guides

During Phase III of the MIA, DOE interviewed manufacturers to gather information on the effects of amended energy conservation standards on revenues and finances, direct employment, capital assets, and industry competitiveness. Before the interviews, DOE distributed separate interview guides for the GSFL and IRL industries. The interview guides provided a starting point to identify relevant issues and help identify the impacts of amended energy conservation standards on individual manufacturers or subgroups of manufacturers in their respective industries. Most of the information DOE received from these meetings is protected by non-disclosure agreements and resides with DOE's contractors. Before each telephone interview or site visit, DOE provided company representatives with an interview guide that included the topics for which DOE sought input. The MIA interview topics included (1) preliminary analysis follow-up, (2) key issues, (3) company overview and organizational characteristics, (4) markups and profitability, (5) shipment projections, (6) financial parameters, (7) conversion costs, (8) cumulative regulatory burden, (9) direct employment impact assessment, (10) manufacturing capacity and non-US sales, (11) impact on competition, and (12) impacts on small business. The interview guides are presented in appendix 13A.

13.2.3 Phase III: Subgroup Analysis

Using average cost and financial assumptions to develop an industry cash-flow model is not adequate for assessing differential impacts among a potential subgroup of manufacturers. Small manufacturers, niche players, or manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively impacted. During interviews, DOE identified one potential manufacturer subgroup (small manufacturers) that could be disproportionately impacted by amended energy conservation standards. As a result, DOE will analyze small business manufacturers as a subgroup.

13.2.3.1 Manufacturing Interviews

The information gathered in Phase I and the cash-flow analysis performed in Phase II are supplemented with information gathered from manufacturer interviews in Phase III. The interview process provides an opportunity for interested parties to express their views on important issues privately, allowing confidential or sensitive information to be considered in the rulemaking process.

DOE used these interviews to tailor the GRIMs to reflect unique financial characteristics of GSFL and IRL manufacturers. DOE contacted companies from its database of manufacturers and interviewed small and large companies, subsidiaries and independent firms, and public and private corporations to provide an accurate representation of the industry. Interviews were scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire was acceptable, DOE sought

interactive interviews, which helped clarify responses and identify additional issues. The resulting information provides valuable inputs to the GRIMs developed for each industry.

13.2.3.2 Revised Industry Cash-Flow Analysis

In Phase II of the MIA, DOE provided manufacturers with preliminary GRIM input financial figures for review and evaluation. During the interviews, DOE requested comments on the values it selected for the parameters. DOE revised its industry cash-flow models based on this feedback. Section 13.4.3 provides more information on how DOE calculated the parameters.

13.2.3.3 Small Business Subgroup

As part of Phase III, DOE investigated whether small businesses should be analyzed as a subgroup. DOE used the Small Business Administration (SBA) small business size standards published on January 7, 2013, as amended, and the North American Industry Classification System (NAICS) code, presented in Table 13.2.1, to determine whether any small entities would be affected by this rulemaking.^a For the product classes under review, the SBA bases its small business definition on the total number of employees for a business, its subsidiaries, and its parent companies. An aggregated business entity with fewer employees than the listed limit is considered a small business.

Table 13.2.1 SBA and NAICS Classifications of Small Businesses Potentially Affected by This Rulemaking

Industry Description	Revenue Limit	Employee Limit	NAICS
Electric Bulb and Part Manufacturing	N/A	1,000	335110

DOE used the National Electrical Manufacturers Association (NEMA)³ member directory, DOE's Compliance Certification Management System (CCMS), the SBA database, information from the previous rulemaking adopting standards for GSFLs and IRLs (hereafter the "2009 Lamps Rule"), individual company websites, and market research tools (*e.g.*, Hoover's reports) to create a list of companies that potentially sell GSFLs or IRLs covered by this rulemaking. Additionally, DOE asked interested parties and industry representatives if they were aware of other small businesses in either industry. DOE contacted select companies on its list, as necessary, to determine whether they met the SBA's definition of a GSFL or IRL small business. DOE screened out companies that did not offer products covered by this rulemaking, did not meet the definition of a "small business," or are foreign owned and operated.

During its research, DOE identified approximately 21 companies that sell GSFLs covered by this rulemaking and qualify as small businesses per the SBA employment threshold for this industry. DOE contacted the GSFL small businesses to solicit feedback on the potential impacts of GSFL energy conservation standards. Two of the GSFL small businesses consented to be interviewed during the MIA interviews. DOE also identified approximately 15 companies that sell IRLs covered by this rulemaking and qualify as a small business per the SBA employment threshold for this industry. DOE contacted the IRL small businesses to solicit feedback on the potential impacts of IRL energy conservation standards. Two of the IRL small businesses

^a The size standards are available on the SBA's website at <http://www.sba.gov/content/table-small-business-size-standards>

consented to being interviewed during the MIA interviews. In addition to posing the standard MIA interview questions, DOE solicited data from manufacturers on differential impacts that these small businesses might experience from amended energy conservation standards. Because DOE was not able to certify that the proposed rulemaking for GSFLs and IRLs would not have a significant economic impact on a substantial number of small entities, DOE has analyzed small businesses as a subgroup for both GSFLs and IRLs. The results of this subgroup analysis are presented in section 13.6.

13.2.3.4 Manufacturing Capacity Impact

One significant outcome of amended energy conservation standards could be the obsolescence of existing manufacturing assets, including tooling and investment. The manufacturer interview guides have a series of questions to help identify impacts of amended standards on manufacturing capacity. These include questions regarding capacity utilization and plant location decisions in the United States and North America (with and without amended standards); the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time changes to existing PPE. DOE's estimates of the one-time capital changes and stranded assets affect the cash-flow estimates in the GSFL and IRL GRIMs. These estimates can be found in section 13.4.8; DOE's discussion of the capacity impacts can be found in section 13.7.2.

13.2.3.5 Employment Impact

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. To assess how domestic direct employment patterns might be affected, the interviews explored current employment trends in the GSFL and IRL industries. The interviews also solicited manufacturer views on changes in employment patterns that may result from more stringent standards. The employment impacts section of the interview guide focused on current employment levels associated with manufacturers at each production facility, expected future employment levels with and without amended energy conservation standards, and differences in workforce skills and issues related to retraining employees. The employment impacts are reported in section 13.7.1.

13.2.3.6 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers due to amended energy conservation standards and other regulatory actions affecting the same products. DOE analyzed the impact on manufacturers of multiple, product-specific regulatory actions. Based on its own research and discussions with manufacturers, DOE identified regulations relevant to GSFL and IRL manufacturers, such as state regulations and other Federal regulations that impact other products made by the same manufacturers. Discussion of the cumulative regulatory burden can be found in section 13.7.3.

13.3 MANUFACTURER IMPACT ANALYSIS KEY ISSUES

Each MIA interview begins by asking: "What are the key issues for your company regarding the energy conservation standard rulemaking?" This question prompts manufacturers to identify the issues they believe DOE should explore and discuss further during the interview.

The following sections describe the most significant issues identified by manufacturers. These summaries are provided in aggregate to protect manufacturer confidentiality.

13.3.1 Rare Earth Oxides in GSFLs

Several manufacturers are concerned that increasing the efficacy of GSFLs in response to amended energy conservation standards will require the use of significantly more rare earth oxides (REOs) in GSFLs. This could expose GSFL manufacturers to the risk of another significant increase in the price of REOs. Over the past several years the price of REOs used in GSFLs has been extremely volatile. In 2011, the price of REOs significantly increased, but has slowly been coming down over the past couple of years. While the current price of many of these REOs has returned to much lower levels than the peak prices experienced between 2010 and 2011, GSFL manufacturers are concerned that the price of REOs could return to those peak prices in the future. GSFL manufacturers are also concerned an increase in the demand for REOs due to amended energy conservation standards could cause the price for these REOs to spike.

Several GSFL manufacturers also noted that amended energy conservation standards for GSFLs could have adverse impacts on the domestic production of GSFLs. China is currently the dominant miner and producer of REOs worldwide and imposes quotas on the export of raw REOs. This drives up the costs for manufacturers of products using REOs that manufacture these products outside of China. As a result, manufacturers pointed out that amended GSFL standards could make it more attractive to manufacture GSFLs in China, rather than domestically, because the price of REOs would likely be much lower in China.

13.3.2 Unknown Impacts of the 2009 Lamps Rule

Several manufacturers expressed concern that amended energy conservation standards for GSFLs and IRLs would be premature given that the last round of DOE energy conservation standards for GSFLs and IRLs required compliance in July 2012. Manufacturers are still unsure how the standards from the 2009 Lamps Rule will ultimately affect their future sales and shipments as consumer preferences shift since there are a relatively large number of alternative lighting options available on the market. Manufacturers noted that they have developed new products to meet the 2009 Lamps Rule standards and are still waiting to see which consumers purchase which types of lamps.

Furthermore, manufacturers stated they have already made significant capital investments in order to be able to produce the more efficacious GSFLs and IRLs required by the 2009 Lamps Rule standards. The capital investments required for IRL production were especially substantial. Manufacturers are concerned that any additional increase in the efficacy of those products due to amended energy conservation standards could potentially strand the substantial capital investments made to comply with the 2009 Lamps Rule, as manufacturers have not yet fully recouped these capital investments. Manufacturers stated that a five year time period between the compliance date of the 2009 Lamps Rule (July 2012) and the estimated compliance date of the current GSFL and IRL rulemaking (2017) is too short for most manufacturers to recoup their capital investments, since manufacturing machinery typically has a much longer useful lifetime than five years.

13.3.3 Technology Shift

Several manufacturers contended that regardless of amended energy conservation standards, a technological shift away from GSFLs and IRLs is already occurring. They pointed out that the market is already moving toward light emitting diodes (LEDs), especially in the commercial sector. Manufacturers are concerned that amended standards would force them to divert resources away from the R&D of more efficacious lighting products, such as LEDs, by forcing manufacturers to spend time and money on GSFLs and IRLs, which have diminishing market shares. This increase in the efficacy of GSFLs and IRLs would increase the end-user price of GSFLs and IRLs, which could ultimately drive consumers to purchase other lighting technologies, like LEDs. This could result in a further stranding of any capital investments made for GSFLs and IRLs.

13.3.4 Impact on Residential Sector

Several manufacturers expressed concern that amended energy conservation standards for GSFLs and IRLs would not achieve substantial energy savings in the residential sector. Residential consumers do not have long operating hours and manufacturers are concerned that they will give up longer life to get a cheaper lamp. Furthermore, manufacturers expressed concern that amended GSFL standards may be overly burdensome by forcing some residential consumers of GSFLs to switch out their entire lighting system (*i.e.*, ballast and fixture) due to replacement lamps being regulated out of production for only minimal energy savings. DOE acknowledges that residential consumers could be differentially impacted by GSFL and IRL standards compared to commercial consumers. DOE analyzed residential and commercial consumers separately in the LCC analysis for GSFLs and IRLs. These results are presented in chapter 8 of this NOPR TSD.

13.4 GRIM INPUTS AND ASSUMPTIONS

The GRIM serves as the main tool for assessing the impacts on industry due to amended energy conservation standards. DOE relies on several sources to obtain inputs for the GRIM. Data and assumptions from these sources are then fed into an accounting model that calculates the industry cash flow both with and without amended energy conservation standards.

13.4.1 Overview of the GRIM

The basic structure of the GRIM, illustrated in Figure 13.4.1, is an annual cash-flow analysis that uses manufacturer prices, manufacturing costs, shipments, and industry financial information as inputs, and accepts a set of regulatory conditions such as changes in costs, investments, and associated margins. The GRIM spreadsheet uses a number of inputs to arrive at a series of annual cash flows, beginning with the base year of the analysis, 2013, and continuing to 2046. The model calculates the INPV by summing the stream of annual discounted cash flows during this period and adding a discounted terminal value.⁴

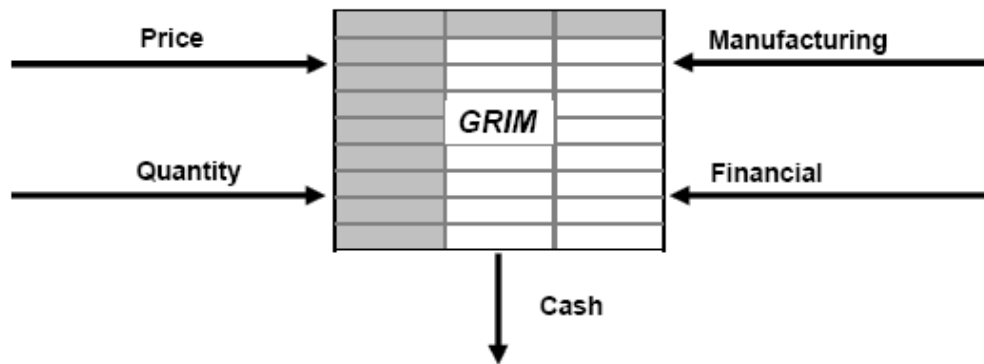


Figure 13.4.1 Using the GRIM to Calculate Cash Flow

The GRIM projects cash flows using standard accounting principles and compares changes in INPV between the base case and the standard-case scenario induced by amended energy conservation standards. The difference in INPV between the base case and the standard case(s) represents the estimated financial impact of the amended energy conservation standard on manufacturers. Appendix 13B provides more technical details and user information for the GRIM.

13.4.2 Sources for GRIM Inputs

The GRIM uses several different sources for data inputs in determining industry cash flow. These sources include corporate annual reports, company profiles, Census data, credit ratings, the shipments model, the engineering analysis, and the manufacturer interviews.

13.4.2.1 Corporate Annual Reports

Corporate annual reports to the SEC (SEC 10-Ks) provided many of the initial financial inputs to the GRIM. These reports exist for publicly held companies and are freely available to the general public. DOE developed initial financial inputs to the GRIM by examining the annual SEC 10-K reports filed by publicly traded manufacturers that produce GSFLs and IRLs, among other products. Since these companies do not provide detailed information about their individual product lines, DOE used financial information at the parent company level as its initial estimates of the financial parameters in the GRIM analysis. These figures were later revised using feedback from interviews to be representative of GSFL and IRL manufacturing. DOE used corporate annual reports to derive the following initial inputs to the GRIM:

- Tax rate
- Working capital
- SG&A
- R&D
- Depreciation
- Capital expenditures
- Net PPE

13.4.2.2 Standard and Poor Credit Ratings

S&P provides independent credit ratings, research, and financial information. DOE relied on S&P reports to determine the industry's average cost of debt when calculating the cost of capital.

13.4.2.3 Shipment Model

The GRIM used shipment projections derived from DOE's shipments model in the NIA. The model relied on historical shipments data for GSFLs and IRLs, the lumen capacity demand per square foot for commercial and residential floor spaces serviced by GSFLs and IRLs, projections from the *Annual Energy Outlook 2013* (AEO 2013), and the LED penetration rate from DOE's Solid-State Lighting Program. Chapter 11 of this NOPR TSD describes the methodology and analytical model DOE used to forecast shipments.

13.4.2.4 Engineering Analysis

The engineering analysis establishes the relationship between end-user price and efficacy level for all GSFLs and IRLs covered in this rulemaking. DOE based its engineering analysis on commercially available lamps that met the design options identified in the technology assessment and screening analysis (chapters 3 and 4 of this NOPR TSD). DOE's engineering approach consisted of the following steps: 1) identifying representative product classes to analyze, 2) selecting baseline lamps, 3) identifying more efficacious substitutes for the baseline lamps, and 4) developing efficacy levels for the representative product classes and scaling those levels to product classes not analyzed. Typically, DOE develops manufacturer production costs (MPCs) for the covered products and uses the prices as an input to the life-cycle cost (LCC) analysis and NIA. However, because GSFLs and IRLs are difficult to reverse-engineer, DOE derived end-user prices as part of the engineering analysis for the lamps covered in this rulemaking. DOE observed a range of end-user prices paid for GSFLs and IRLs depending on the distribution channel through which the lamps are purchased. DOE then developed three sets of discounts from the manufacturer blue-book prices representing low (state procurement), medium (electrical distributors and big box retailers), and high (Internet retailers) lamp prices for both GSFLs and IRLs. See chapter 5 of this NOPR TSD for a complete discussion of the engineering analysis and chapter 7 of this NOPR TSD for a discussion on product price determination.

13.4.2.5 Manufacturer Interviews

During the course of the MIA, DOE conducted interviews with a representative cross-section of manufacturers. DOE also interviewed manufacturers that account for a significant portion of sales in every product class. During these discussions, DOE obtained information to determine and verify GRIM input assumptions in each industry. Key topics discussed during the interviews and reflected in the GRIM include:

- capital conversion costs (one-time investments in PPE);
- product conversion costs (one-time investments in research, product development, testing, certification, and marketing);

- product cost structure, or the portion of the MPCs related to materials, labor, overhead, and depreciation costs;
- possible profitability impacts;
- impacts on small businesses; and
- cost-efficacy curves calculated in the engineering analysis.

13.4.3 Financial Parameters

Table 13.4.1 below provides financial parameters for three public companies engaged in manufacturing and selling GSFLs and IRLs. The values listed are averages over a seven-year period (2006 to 2012).

Table 13.4.1 GRIM Financial Parameters Based on 2006–2012 Weighted Company Financial Data

Parameter	Weighted Average	Manufacturer		
		A	B	C
Tax Rate % of taxable income	31.2%	16.0%	49.2%	28.5%
Working Capital % of revenues	4.9%	(6.2%)	17.3%	3.8%
SG&A % of revenues	17.9%	14.1%	24.0%	15.5%
R&D % of revenues	4.5%	3.3%	5.0%	5.0%
Depreciation % of revenues	3.5%	2.0%	4.9%	3.8%
Capital Expenditures % of revenues	3.4%	2.7%	3.7%	3.9%
Net PPE % of revenues	18.2%	13.1%	28.0%	13.6%

During interviews, GSFL and IRL manufacturers were asked to provide their own figures for the parameters listed in Table 13.4.1. Where applicable, DOE adjusted the parameters in the GRIM using this feedback, more recent data from publicly traded companies, and values used during the 2009 Lamps Rule to reflect the current GSFL and IRL industries. Table 13.4.2 presents the revised parameters used for GSFL and IRL manufacturers for this notice of proposed rulemaking (NOPR).

Table 13.4.2 GRIM Revised GSFL and IRL Industry Financial Parameters

Parameter	Revised Estimates
Tax Rate % of taxable income	33.3%
Working Capital % of revenues	16.0%
SG&A % of revenues	15.0%
R&D % of revenues	4.8%
Depreciation % of revenues	4.2%
Capital Expenditures % of revenues	4.8%
Net PPE % of revenues	18.4%

13.4.4 Corporate Discount Rate

DOE used the weighted average cost of capital (WACC) as the discount rate to calculate the INPV. A company's assets are financed by a combination of debt and equity. The WACC is the total cost of debt and equity weighted by their respective proportions in the capital structure of the industry. DOE estimated the WACC for the GSFL and IRL industries based on several representative companies, using the following formula:

$$\text{WACC} = \text{After-Tax Cost of Debt} \times (\text{Debt Ratio}) + \text{Cost of Equity} \times (\text{Equity Ratio})$$

Eq. 13.1

The cost of equity is the rate of return that equity investors (including, potentially, the company) expect to earn on a company's stock. These expectations are reflected in the market price of the company's stock. The capital asset pricing model (CAPM) provides one widely used means to estimate the cost of equity. According to the CAPM, the cost of equity (expected return) is:

$$\text{Cost of Equity} = \text{Riskless Rate of Return} + \beta \times \text{Risk Premium}$$

Eq. 13.2

Where:

Riskless rate of return = the rate of return on a "safe" benchmark investment, typically considered the short-term Treasury Bill (T-Bill) yield,

Risk premium = the difference between the expected return on stocks and the riskless rate, and

Beta (β) = the correlation between the movement in the price of the stock and that of the broader market. In this case, Beta equals one if the stock is perfectly correlated with the S&P 500 market index. A Beta lower than one means the stock is less volatile than the market index.

DOE determined that the industry average cost of equity for the GSFL and IRL industries is 14.4 percent.

Table 13.4.3 Cost of Equity Calculation

Parameter	Industry-Weighted Average %	Manufacturer		
		A	B	C
(1) Average Beta	1.5	NA	1.8	1.8
(2) Yield on 10-Year T-Bill (1928-2011)	5.2	-	-	-
(3) Market Risk Premium (1928-2011)	6.1	-	-	-
Cost of Equity (2)+[(1)*(3)]	14.4	-	-	-
Equity/Total Capital	78.6	91.6	45.9	45.9

Bond ratings are a tool to measure default risk and arrive at a cost of debt. Each bond rating is associated with a particular spread. One way of estimating a company's cost of debt is to treat it as a spread (usually expressed in basis points) over the risk-free rate. DOE used this method to calculate the cost of debt for all three manufacturers by using S&P ratings and adding the relevant spread to the risk-free rate.

In practice, investors use a variety of different maturity Treasury bonds to estimate the risk-free rate. DOE used the 10-year Treasury bond return because it captures long-term inflation expectations and is less volatile than short-term rates. The risk-free rate is estimated to be approximately 5.2 percent, which is the average 10-year Treasury bond return between 1928 and 2012.

For the cost of debt, S&P's Credit Services provided the average spread of corporate bonds for the three public manufacturers. DOE added the industry-weighted average spread to

the average T-Bill rate. Since proceeds from debt issuance are tax deductible, DOE adjusted the gross cost of debt by the industry average tax rate to determine the net cost of debt for the industry. Table 13.4.4 presents the derivation of the cost of debt and the capital structure of the industry (*i.e.*, the debt ratio (debt/total capital)).

Table 13.4.4 Cost of Debt Calculation

Parameter	Industry-Weighted Average %	Manufacturer		
		A	B	C
S&P Bond Rating	-	AA	A-	A+
(1) Yield on 10-Year T-Bill (1928-2011)	5.2%	-	-	-
(2) Gross Cost of Debt	6.0%	5.8%	6.3%	6.0%
(3) Tax Rate	31.2%	16.0%	49.2%	28.5%
Net Cost of Debt (2) x (1-(3))	4.1%	4.9%	3.2%	4.3%
Debt/Total Capital	21.4%	8.5%	20.2%	35.0%

Using public information for these three companies, the initial estimate for the GSFL and IRL industry WACC was approximately 12.2 percent. Subtracting an inflation rate of 3.1 percent between 1928 and 2012, the inflation-adjusted WACC, which was the initial estimate of the discount rate used in the straw-man GRIM, was 9.2 percent. DOE asked for feedback on the 9.2 percent discount rate during manufacturer interviews. Most manufacturers agreed the 9.2 percent discount rate was appropriate to use for both the GSFL and IRL markets.

13.4.5 Trial Standard Levels

DOE developed TSLs for GSFLs consistent with the engineering analysis. DOE analyzed five representative product classes for GSFLs. Table 13.4.5 shows the efficacy levels at each TSL for the GSFLs analyzed by DOE. For more information regarding the creation of TSLs for GSFLs see chapter 10 of this NOPR TSD.

Table 13.4.5 Trial Standard Levels for GSFLs

Product Class	Representative Product Class Description	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
1	4-foot MBP, CCT ≤ 4,500 K	EL 0	EL 0	EL 1	EL 2	EL 2
2	8-foot SP slimline, CCT ≤ 4,500 K	EL 0	EL 1	EL 0	EL 0	EL 2
3	8-foot RDC HO, CCT ≤ 4,500 K	EL 1	EL 2	EL 1	EL 1	EL 2
4	4-foot T5 MiniBP SO, CCT ≤ 4,500 K	EL 1	EL 1	EL 1	EL 1	EL 2
5	4-foot T5 MiniBP HO, CCT ≤ 4,500 K	EL 1	EL 1	EL 1	EL 1	EL 1

TSL 1 sets the efficacy level at baseline for two product classes (4-foot medium bipin (MBP) and 8-foot single pin (SP) slimline) and efficacy level (EL) 1 for three product classes (8-

foot recessed double contact (RDC) high output (HO), 4-foot T5 miniature bipin (MiniBP) standard output (SO), and 4-foot T5 MiniBP HO). EL 1 for the 4-foot T5 MiniBP HO product class represents the maximum technologically feasible (“max tech”) efficacy level.

TSL 2 sets the efficacy level at baseline for one product class (4-foot MBP), EL 1 for three product classes (8-foot SP slimline, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO), and EL 2 for one product class (8-foot RDC HO). EL 1 for the 4-foot T5 MiniBP HO product class and EL 2 for the 8-foot RDC HO product class represent the max tech efficacy levels.

TSL 3 sets the efficacy level at baseline for one product class (8-foot SP slimline) and EL 1 for four product classes (4-foot MBP 8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO). EL 1 for the 4-foot T5 MiniBP HO product class represents the max tech efficacy level.

TSL 4 sets the efficacy level at baseline for one product class (8-foot SP slimline), EL 1 for three product classes (8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO), and EL 2 for one product class (4-foot MBP). EL 1 for the 4-foot T5 MiniBP HO product class and EL 2 for the 4-foot MBP product class represent the max tech efficacy levels.

TSL 5 sets the efficacy level at the max tech for all product classes. This represents EL 1 for one product class (4-foot T5 MiniBP HO) and EL 2 for five product classes (4-foot MBP, 8-foot SP slimline, 8-foot RDC HO, and 4-foot T5 MiniBP SO).

Consistent with the engineering analysis, DOE developed TSLs for IRLs. DOE analyzed one representative product class for IRLs. Table 13.4.6 shows the efficacy level at TSL 1 for IRLs analyzed by DOE. For more information regarding the creation of TSLs for IRLs see chapter 10 of this NOPR TSD.

Table 13.4.6 Trial Standard Levels for IRLs

Product Class	Representative Product Class Description	TSL 1
1	Standard Spectrum, > 2.5 inches, < 125 V	EL 1

TSL 1 sets the efficacy level at EL 1, the max tech level for the IRL representative product class.

13.4.6 NIA Shipment Forecast

The GRIMs estimate manufacturer revenues based on total unit-shipment forecasts and the distribution of these values by efficacy level. Changes in the efficacy mix at each standard level are a key driver of manufacturer finances. For this analysis, the GRIMs used the NIA’s annual shipment forecasts from 2013 to 2046, the end of the analysis period. For the shipments analysis, DOE first established a lumen capacity demand per square foot for commercial and residential spaces serviced by GSFLs and IRLs. While this lumen capacity per square foot demand is assumed to remain unchanged over the analysis period, the total lumen demand grows proportionally with the growth of new commercial and residential floor space, as projected by [AEO 2013](#). DOE also expects the lighting demand for GSFLs and IRLs to be eroded by increased penetration of LEDs into the market. This LED penetration rate for the reference

shipment scenario is based on the rate forecasted in DOE's Solid-State Lighting Program. Overall, while demand for lighting is expected to increase for the entire economy as the amount of floor space increases, the demand for GSFL and IRL specific lighting is projected to decline due to the increased penetration of alternative lighting sources such as LEDs. The assumptions and methodology that drive this analysis are described in chapter 11 of this NOPR TSD.

13.4.7 Production Costs

During the engineering analysis, DOE developed the end-user price for the representative product classes at each EL analyzed. To get from the end-user price to the manufacturer selling price (MSP), the price at which manufacturers sell lamps to their customer, DOE calculated the distribution chain markup for the GSFL and IRL industries. DOE examined the SEC 10-Ks of publicly traded big box retail stores to determine the average retail markup for the medium end-user price distribution chain. DOE found the typical retail markup for big box stores was 1.52. DOE divided the medium end-user price for all GSFLs and IRLs by this value to arrive at MSPs for all GSFLs and IRLs.

DOE also examined the SEC 10-Ks of all publicly traded GSFL and IRL manufacturers to estimate the average GSFL and IRL manufacturer markup. The manufacturer markup represents the markup lamp manufacturers apply to their MPCs to arrive at the MSPs. This is different than the distribution chain markup, which is what retail stores markup the MSP to arrive at the end-user price. Based on SEC 10-Ks, DOE found the typical manufacturer markup for GSFL and IRL manufacturers on a corporate level was 1.58. During manufacturer interviews, DOE asked manufacturers if 1.58 was an appropriate markup to use for GSFLs and IRLs. Based on manufacturer feedback that the 1.58 manufacturer markup was too high for both GSFLs and IRLs and should be lowered, DOE revised the manufacturer markup for both GSFLs and IRLs to be 1.52. The 1.52 figure is the same manufacturer markup used for these products in the 2009 Lamps Rule.

For GSFLs, DOE estimated the percentage of the MPC that corresponds to materials, labor, depreciation, and overhead necessary to produce GSFLs at each EL. For the GSFL MPC, DOE estimated the absolute dollar amount of labor and overhead remains constant as the efficacy of the GSFL increases within a representative product class. This means as the overall price of the GSFL increases due to increased lamp efficacy, the percentage of the MPC that corresponds to labor and overhead decreases. DOE also estimated that the percentage of the MPC that corresponds to depreciation remains constant as the efficacy of the lamp increases within a representative product class. This means as the overall price of the GSFL increases due to the increased lamp efficacy, the absolute dollar amount of depreciation also increases proportionally to the MPC. DOE estimated that the remainder of the MPC is attributed to materials. Materials account for a greater percentage of the MPC as the efficacy of the lamp increases, as well as a larger absolute dollar amount within the MPC.

Table 13.4.7 through Table 13.4.11 show the average production cost estimates for GSFLs used in the GRIM for each representative GSFL product class at each efficacy level.

Table 13.4.7 Manufacturer Production Cost Breakdown (2012\$) for 4-Foot MBP GSFL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$0.93	\$0.69	\$0.12	\$0.47	\$2.21	1.52	\$3.36
EL 1	\$1.15	\$0.69	\$0.13	\$0.47	\$2.44	1.52	\$3.71
EL 2_93	\$3.44	\$0.69	\$0.26	\$0.47	\$4.86	1.52	\$7.39
EL 2_95	\$2.83	\$0.69	\$0.22	\$0.47	\$4.22	1.52	\$6.41
EL 2_96	\$2.29	\$0.69	\$0.19	\$0.47	\$3.64	1.52	\$5.53

Table 13.4.8 Manufacturer Production Cost Breakdown (2012\$) for 8-Foot SP slimline GSFL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$1.95	\$1.45	\$0.25	\$0.99	\$4.64	1.52	\$7.05
EL 1	\$2.48	\$1.45	\$0.28	\$0.99	\$5.19	1.52	\$7.89
EL 2_99	\$3.50	\$1.45	\$0.33	\$0.99	\$6.27	1.52	\$9.53
EL 2_105	\$5.29	\$1.45	\$0.43	\$0.99	\$8.16	1.52	\$12.40
EL 2_108	\$6.76	\$1.45	\$0.52	\$0.99	\$9.72	1.52	\$14.77

Table 13.4.9 Manufacturer Production Cost Breakdown (2012\$) for 8-Foot RDC HO GSFL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$1.61	\$1.20	\$0.20	\$0.81	\$3.82	1.52	\$5.81
EL 1	\$3.51	\$1.20	\$0.31	\$0.81	\$5.83	1.52	\$8.86
EL 2	\$4.95	\$1.20	\$0.39	\$0.81	\$7.35	1.52	\$11.17

Table 13.4.10 Manufacturer Production Cost Breakdown (2012\$) for 4-Foot T5 MiniBP SO GSFL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$0.76	\$0.57	\$0.10	\$0.38	\$1.81	1.52	\$2.75
EL 1	\$1.54	\$0.57	\$0.14	\$0.38	\$2.63	1.52	\$4.00
EL 2_109	\$2.01	\$0.57	\$0.17	\$0.38	\$3.13	1.52	\$4.76
EL 2_111	\$2.64	\$0.57	\$0.20	\$0.38	\$3.79	1.52	\$5.76
EL 2_116	\$3.19	\$0.57	\$0.23	\$0.38	\$4.37	1.52	\$6.64

Table 13.4.11 Manufacturer Production Cost Breakdown (2012\$) for 4-Foot T5 MiniBP HO GSFL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$1.05	\$0.78	\$0.13	\$0.53	\$2.50	1.52	\$3.80
EL 1_92	\$2.65	\$0.78	\$0.22	\$0.53	\$4.19	1.52	\$6.37
EL 1_102.0	\$3.84	\$0.78	\$0.29	\$0.53	\$5.44	1.52	\$8.27
EL 1_102.1	\$4.42	\$0.78	\$0.32	\$0.53	\$6.06	1.52	\$9.21

DOE also estimated the percentage of the MPC that corresponds to materials, labor, depreciation, and overhead necessary to produce IRLs at each EL. For the IRL MPC, DOE estimated the percentage of materials, labor, depreciation, and overhead remains constant as the efficacy of the IRL increases within the representative product class. This means as the overall

price of the IRL increases due to the increased lamp efficacy, the absolute dollar amount of materials, labor, depreciation, and overhead also increase proportionally to the MPC.

Table 13.4.12 shows the average production cost estimates for IRLs used in the GRIM for the representative IRL product class at each efficacy level.

Table 13.4.12 Manufacturer Production Cost Breakdown (2012\$) for Standard Spectrum; > 2.5 Inch Diameter; < 125 V IRL

EL	Materials	Labor	Depreciation	Overhead	MPC	Markup	MSP
Baseline	\$2.47	\$0.86	\$0.21	\$0.21	\$3.74	1.52	\$5.68
EL 1_2500	\$3.14	\$1.09	\$0.26	\$0.26	\$4.75	1.52	\$7.22
EL 1_4200	\$3.62	\$1.26	\$0.30	\$0.30	\$5.49	1.52	\$8.34

13.4.8 Capital and Product Conversion Costs

DOE expects amended energy conservation standards of GSFLs and IRLs to cause manufacturers to incur conversion costs to bring their production facilities and product designs into compliance with amended standards. For the MIA, DOE classified these conversion costs into two major groups: (1) capital conversion costs and (2) product conversion costs. Capital conversion costs are investments in property, plant, and equipment necessary to adapt or change existing production facilities such that new product designs can be fabricated and assembled. Product conversion costs are investments in research, development, testing, marketing, certification, and other non-capitalized costs necessary to make product designs comply with amended standards.

Using feedback from manufacturer interviews, DOE conducted both top-down and bottom-up analyses to calculate the capital and product conversion costs for GSFL and IRL manufacturers. DOE then adjusted these conversion costs if there were any discrepancies between the two methods to arrive at a final capital and product conversion cost estimate for each GSFL and IRL product class at each EL.

To conduct the top-down analysis, DOE asked manufacturers during manufacturer interviews to estimate the total capital and product conversion costs they would need to incur to be able to produce each GSFL and IRL product class at specific ELs. DOE then summed these values provided by manufacturers to arrive at total top-down industry conversion costs for GSFLs and IRLs.

To conduct the bottom-up analysis, DOE used manufacturer input from manufacturer interviews regarding the types and dollar amounts of discrete capital and product expenditures that would be necessary to convert specific production lines for GSFLs or IRLs to each EL. GSFL manufacturers identified upgrading and recalibrating production automation systems as the primary capital cost that would be necessary to meet higher efficacy levels for GSFLs. IRL manufacturers identified several potential capital costs that could be required to meet higher efficacy levels for IRLs. These included purchasing new burner coating machines, increasing the capacity of existing burners, purchasing reflector coating machines, and purchasing coiling machines, as well as other retooling costs. The two main types of product conversion costs for

GSFLs and IRLs that manufacturers shared with DOE during manufacturer interviews were the engineering hours necessary to redesign lamps to meet higher efficacy standards and the testing and certification costs necessary to comply with higher efficacy standards. Once DOE had compiled these capital and product conversion costs, DOE then took average values (*i.e.*, average number of hours or average dollar amounts) based on the range of responses given by manufacturers for each capital and product conversion cost at each EL.

The bottom-up conversion costs estimates DOE created were consistent with the manufacturer top-down estimates provided, so DOE used these conversion cost estimates as the final values for each GSFL and IRL product class at each EL in the MIA.

For GSFLs, DOE's estimates of the capital and product conversion costs for GSFL representative product classes can be found in Table 13.4.13 and Table 13.4.14.

Table 13.4.13 Capital Conversion Costs for all GSFLs by TSL

Representative Product Class Description	TSL 1 (2012\$ millions)	TSL 2 (2012\$ millions)	TSL 3 (2012\$ millions)	TSL 4 (2012\$ millions)	TSL 5 (2012\$ millions)
4-foot MBP	-	-	\$2.0	\$4.5	\$4.5
8-foot SP Slimline & 8-foot RDC HO	\$1.0	\$11.0	\$1.0	\$1.0	\$11.0
4-foot T5 Mini BP SO & 4-foot T5 MiniBP HO	-	-	-	-	\$14.0
Total	\$1.0	\$11.0	\$3.0	\$5.5	\$29.5

Table 13.4.14 Product Conversion Costs for all GSFLs by TSL

Representative Product Class Description	TSL 1 (2012\$ millions)	TSL 2 (2012\$ millions)	TSL 3 (2012\$ millions)	TSL 4 (2012\$ millions)	TSL 5 (2012\$ millions)
4-foot MBP	-	-	\$2.5	\$4.6	\$4.6
8-foot SP Slimline	-	\$1.0	-	-	\$1.0
8-foot RDC HO	\$0.3	\$0.4	\$0.3	\$0.3	\$0.4
4-foot T5 Mini BP SO	\$0.3	\$0.3	\$0.3	\$0.3	\$0.8
4-foot T5 MiniBP HO	\$0.4	\$0.4	\$0.4	\$0.4	\$0.4
Total	\$0.9	\$2.0	\$5.3	\$7.5	\$9.1

For IRLs, DOE's estimates of the capital and product conversion costs for the IRL representative product class can be found in Table 13.4.15 and Table 13.4.16.

Table 13.4.15 Capital Conversion Costs for all IRLs by TSL

Representative Product Class Description	TSL 1 (2012\$ millions)
Standard Spectrum; > 2.5 Inch Diameter; < 125 V	\$65.4

Table 13.4.16 Product Conversion Costs for all IRLs by TSL

Representative Product Class Description	TSL 1 (2012\$ millions)
Standard Spectrum; > 2.5 Inch Diameter; < 125 V	\$6.1

13.4.9 Markup Scenarios

DOE used two standards case markup scenarios to represent the uncertainty about the impacts of amended energy conservation standards on prices and profitability. In the base case, DOE used the same baseline markups for all GSFL and IRL representative product classes. In the standards case, DOE modeled two markup scenarios to represent the uncertainty about the potential impacts on prices and profitability following the implementation of amended energy conservation standards: (1) a flat, or preservation of gross margin, markup scenario and (2) a preservation of operating profit markup scenario. These scenarios lead to different markup values, which when applied to the inputted MPCs, result in varying revenue and cash-flow impacts.

13.4.9.1 Flat Markup Scenario

Under the flat, or preservation of gross margin, markup scenario DOE applied a single uniform markup across all representative product classes and efficacy levels. As production costs increase with efficacy, this scenario implies that the absolute dollar markup will increase as well. Based on publicly available financial information for manufacturers of GSFLs and IRLs and comments from manufacturer interviews, DOE assumed the non-production cost markup—which includes SG&A expenses; R&D expenses; interest; and profit—to be 1.52 for all GSFL and IRL representative product classes. Because this markup scenario assumes that manufacturers would be able to maintain their gross margin percentage as production costs increase in response to amended standards, it represents the upper bound to industry profitability under amended standards.

13.4.9.2 Preservation of Operating Profit Markup Scenario

DOE implemented the preservation of operating profit markup scenario because manufacturers stated that in the standards case, they do not expect to be able to mark up the full cost of production given the highly competitive market. The preservation of operating profit markup scenario assumes that manufacturers are able to maintain only the base case total operating profit in absolute dollars in the standards case, despite higher production costs and investment. The base case total operating profit is derived from marking up the cost of goods sold for each product by a flat percentage (the flat markup discussed above) to cover standard SG&A expenses, R&D expenses, and profit. DOE adjusted the manufacturer markups in the GRIM at each TSL to yield approximately the same earnings before interest and taxes in the standards case in the year after the compliance date of the amended standards as in the base case. DOE altered the markups only for the minimally compliant products in this scenario, with margin impacts not occurring for products that already exceed the amended standards. The preservation of operating profit markup scenario represents the lower bound of industry profitability following amended standards. Under this scenario, manufacturers are not able to earn additional operating profit on higher production costs and the investments required to comply with amended standards, like they are in the flat, or preservation of gross margin markup scenario. However, manufacturers are able to maintain the same operating profit in the standards case as they would have earned in the base case.

For GSFLs, Table 13.4.17 through Table 13.4.21 lists the representative product classes DOE analyzed with the corresponding preservation of operating profit markups at each selected EL.

Table 13.4.17 Preservation of Operating Profit Markups for 4-Foot MBP GSFLs, CCT ≤ 4,500 K

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.520		
EL 1	1.520	1.465	
EL 2	1.520	1.520	1.432

Table 13.4.18 Preservation of Operating Profit Markups for 8-Foot SP Slimline GSFLs, CCT ≤ 4,500 K

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.520		
EL 1	1.520	1.466	
EL 2	1.520	1.520	1.460

Table 13.4.19 Preservation of Operating Profit Markups for 8-Foot RDC HO GSFLs, CCT ≤ 4,500 K

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.520		
EL 1	1.520	1.425	
EL 2	1.520	1.520	1.433

Table 13.4.20 Preservation of Operating Profit Markups for 4-Foot T5 MiniBP SO GSFLs, CCT ≤ 4,500 K

EL	Markups by Selected EL		
	Baseline	EL 1	EL 2
Baseline	1.520		
EL 1	1.520	1.472	
EL 2	1.520	1.520	1.442

Table 13.4.21 Preservation of Operating Profit Markups for 4-Foot T5 Mini BP HO GSFLs, CCT ≤ 4,500 K

EL	Markups by Selected EL	
	Baseline	EL 1
Baseline	1.520	
EL 1	1.520	1.452

For IRLs, Table 13.4.22 lists the representative product class DOE analyzed with the corresponding preservation of operating profit markups at each EL.

Table 13.4.22 Preservation of Operating Profit Markups for Standard Spectrum; > 2.5 Inch Diameter; < 125 V IRLs

EL	Markups by Selected EL	
	Baseline	EL 1
Baseline	1.520	
EL 1	1.520	1.502

13.5 INDUSTRY FINANCIAL IMPACTS

Using the inputs and scenarios described in the previous sections, the GRIMs estimated indicators of financial impacts on the GSFL and IRL industries. The following sections detail additional inputs and assumptions for GSFLs and IRLs. The main results of the MIA are also reported in this section. The MIA consists of two key financial metrics: INPV and annual cash flows.

13.5.1 Impacts on Industry Net Present Value

The INPV measures the industry value and is used in the MIA to compare the economic impacts of different TSLs in the standards case. The INPV is different from DOE's net present value, which is applied to the U.S. economy. The INPV is the sum of all net cash flows discounted at the industry's cost of capital, or discount rate. The GSFL and IRL GRIMs estimate cash flows from 2013 to 2046. This timeframe models both the short-term impacts on the industries from the announcement of the standard until the compliance date (2014 until an estimated compliance date of 2017) and a long-term assessment over the 30-year analysis period used in the NIA (2017 – 2046).

In the MIA, DOE compares the INPV of the base case (no amended energy conservation standards) to that of each TSL in the standards case. The difference between the base case and a standards case INPV is an estimate of the economic impacts that implementing that particular TSL would have on the industry. For the GSFL and IRL industries, DOE examined the two markup scenarios described above, the flat markup scenario (preservation of gross margin percentage) and the preservation of operating profit markup scenario.

For GSFLs Table 13.5.1 and Table 13.5.2 provide the INPV estimates for the two markup scenarios for the GSFL industry.

Table 13.5.1 Changes in Industry Net Present Value for GSFLs – Flat Markup Scenario

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	(2012\$ millions)	\$1,542.5	\$1,584.4	\$1,580.3	\$1,663.1	\$1,901.1	\$1,939.7
Change in INPV	(2012\$ millions)	-	\$41.8	\$37.8	\$120.5	\$358.5	\$397.1
	(%)	-	2.7%	2.5%	7.8%	23.2%	25.7%

Table 13.5.2 Changes in Industry Net Present Value for GSFLs – Preservation of Operating Profit Markup Scenario

	Units	Base Case	Trial Standard Level				
			1	2	3	4	5
INPV	(2012\$ millions)	\$1,542.5	\$1,541.7	\$1,533.4	\$1,531.0	\$1,519.6	\$1,502.6
Change in INPV	(2012\$ millions)	-	\$(0.9)	\$(9.2)	\$(11.5)	\$(22.9)	\$(39.9)
	(%)	-	-0.1%	-0.6%	-0.7%	-1.5%	-2.6%

For IRLs Table 13.5.3 and Table 13.5.4 provide the INPV estimates for the two markup scenarios for the IRL industry.

Table 13.5.3 Changes in Industry Net Present Value for IRLs – Flat Markup Scenario

	Units	Base Case	Trial Standard Level
			1
INPV	(2012\$ millions)	\$176.0	\$128.6
Change in INPV	(2012\$ millions)	-	\$(47.5)
	(%)	-	-27.0%

Table 13.5.4 Changes in Industry Net Present Value for IRLs – Preservation of Operating Profit Markup Scenario

	Units	Base Case	Trial Standard Level
			1
INPV	(2012\$ millions)	\$176.0	\$124.2
Change in INPV	(2012\$ millions)	-	\$(51.8)
	(%)	-	-29.5%

13.5.2 Impacts on Annual Cash Flow

While INPV is useful for evaluating the long-term effects of amended energy conservation standards, short-term changes in cash flow are also important indicators of the industry's financial situation. For example, a large investment over one or two years could strain the industry's access to capital. Consequently, the sharp drop in financial performance could cause investors to flee, even though recovery may be possible. Thus, a short-term disturbance can have long-term effects that the INPV cannot capture. To get an idea of the behavior of annual free cash flows, Figure 13.5.1 through Figure 13.5.3 below present the annual free cash flows from 2013 through 2046 for the base case and different TSLs in the standards case.

Annual cash flows are discounted to the base year, 2012. Between 2014 and the 2017 compliance date of the amended energy conservation standards, cash flows are driven by the level of conversion costs and the proportion of these investments spent every year. After the standard announcement date (*i.e.*, the publication date of the final rule), industry cash flows begin to decline as companies use their financial resources to prepare for the amended energy conservation standards. The more stringent the amended energy conservation standards, the greater the impact on industry cash flows in the years leading up to the compliance date, as

product conversion costs lower cash inflows from operations and capital conversion costs increase cash outflows for capital expenditures.

Free cash flow in the year the amended energy conservation standards take effect is driven by two competing factors. In addition to capital and product conversion costs, amended energy conservation standards could create stranded assets (*i.e.*, tooling and equipment that would have enjoyed longer use if the energy conservation standards had not made them obsolete). In this year, manufacturers write down the remaining book value of existing tooling and equipment whose value is affected by the amended energy conservation standards. This one-time write-down acts as a tax shield that alleviates decreases in cash flow from operations in the year of the write-down. In this year, there is also an increase in working capital that reduces cash flow from operations. A large increase in working capital is needed due to more costly production components and materials, higher inventories of more expensive products, and higher accounts receivable for more expensive products. Depending on these two competing factors, cash flow can either be positively or negatively affected in the year the standards takes effect.

In the years following the compliance date of the standards, the impact on cash flow depends on the operating revenue. In the flat markup scenario, the manufacture markup is held constant to yield the same gross margin percentage in the standards case at each TSL as in the base case in the year after the standards take effect. The implicit assumption is that manufacturers can freely pass on and mark up higher cost units. The result under this scenario is that operating cash flow increases (in absolute terms) as revenue increases. At the highest TSLs where MPCs dramatically increase, this scenario drives large increases in operating cash flow relative to the base case. The larger the production cost increase, the more likely it is that the increase in operating cash flow after the standards take effect will outweigh the initial conversion costs.

Under the preservation of operating profit scenario, cash flow decreases at each TSL in the standards case compared to the base case because the absolute dollar amount of the gross margin does not change despite an increase in sales and cost of goods sold. Therefore, the gross margin percentage is reduced.

For GSFLs Figure 13.5.1 and Figure 13.5.3 present the annual free cash flows for the GSFL industry.

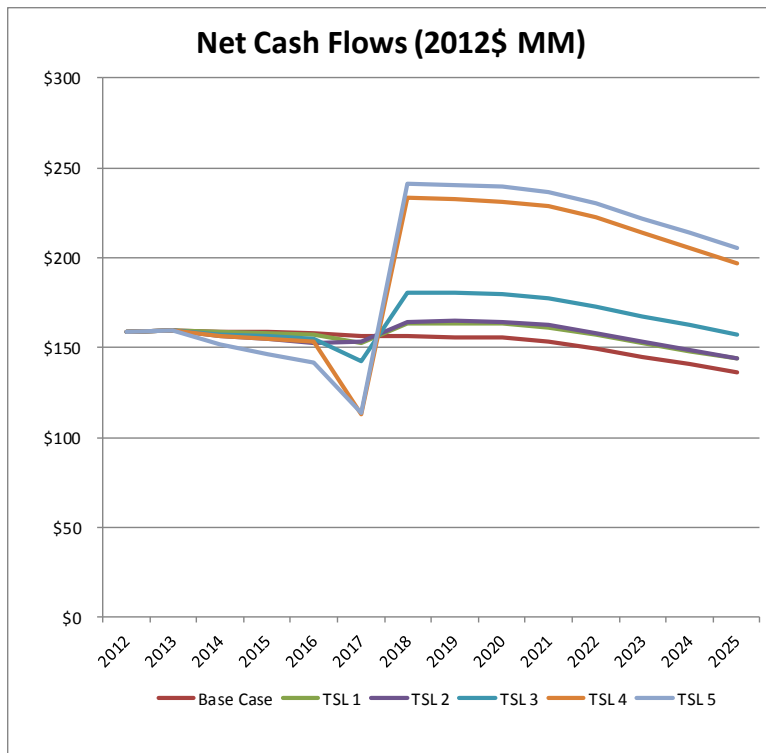


Figure 13.5.1 Annual Industry Free Cash Flows for GSFL - Flat Markup Scenario

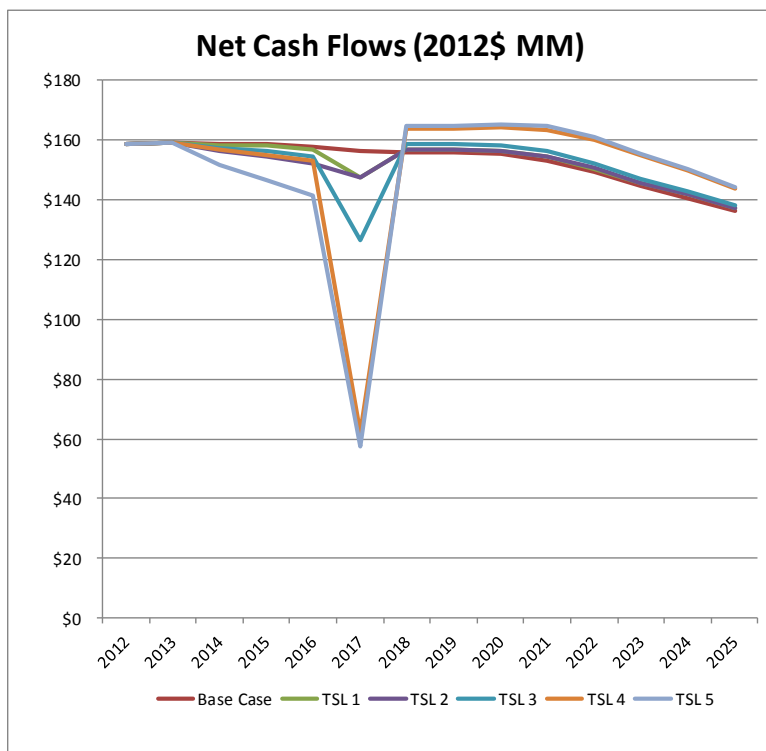


Figure 13.5.2 Annual Industry Free Cash Flows for GSFLs – Preservation of Operating Profit Markup Scenario

For IRLs Figure 13.5.3 and Figure 13.5.4 present the annual free cash flows for the IRL industry.

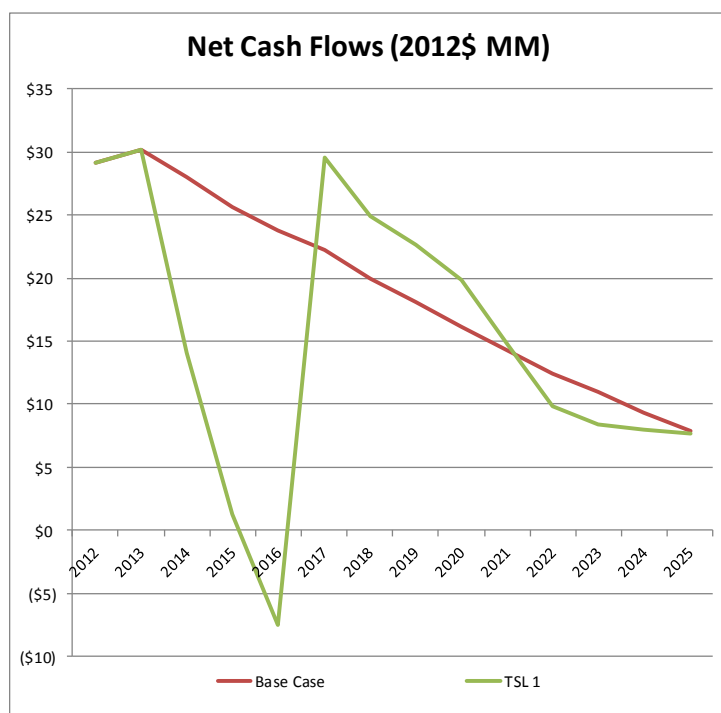


Figure 13.5.3 Annual Industry Free Cash Flows for IRLs – Flat Markup Scenario

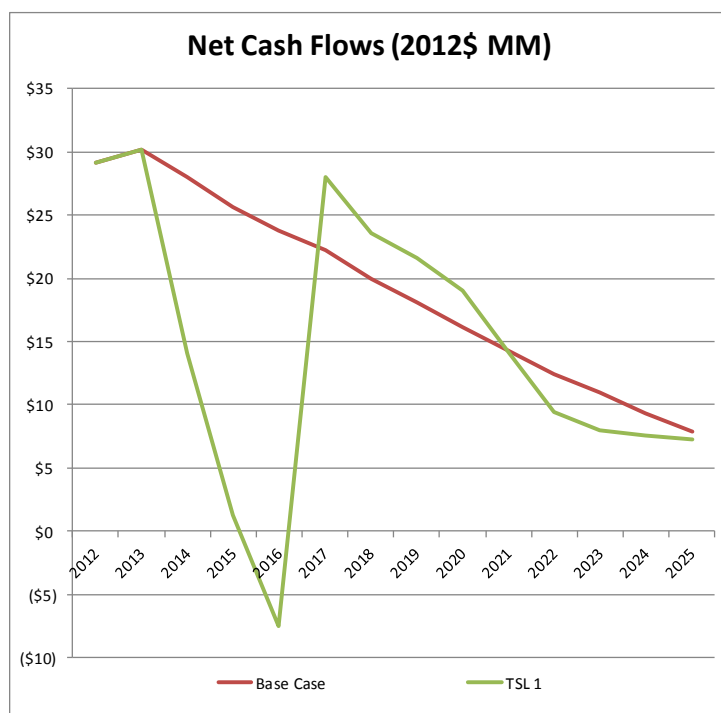


Figure 13.5.4 Annual Industry Free Cash Flows for IRLs – Preservation of Operating Profit Markup Scenario

13.6 IMPACTS ON MANUFACTURER SUBGROUPS

As described in Section 13.2.3 above, DOE identified one subgroup of GSFL and IRL manufacturers: small businesses. The results of this subgroup analysis are described below.

13.6.1 Impacts on Small Business Manufacturers

13.6.1.1 Description and Estimated Number of Small Entities Regulated

DOE conducted a more focused inquiry on the companies that could be small businesses of GSFLs and IRLs covered by this rulemaking. To estimate the number of companies that could be small business manufacturers of GSFLs and IRLs covered by this rulemaking, DOE conducted a market survey using publicly available information. DOE's research involved industry trade association membership directories (including NEMA), information from previous rulemakings, individual company websites, SBA's database, and market research tools (*e.g.*, Hoover's reports). DOE also asked stakeholders and industry representatives if they were aware of any small manufacturers during manufacturer interviews and DOE public meetings. DOE used information from these sources to create a list of companies that potentially manufacture or sell GSFLs or IRLs and would be impacted by this rulemaking. As necessary, DOE contacted companies to determine whether they met the SBA's definition of a small business manufacturer of GSFLs or IRLs. DOE screened out companies that do not offer products covered by this rulemaking, do not meet the definition of a "small business," or are completely foreign owned and operated.

For GSFLs, DOE initially identified a total of 47 potential companies that sell GSFLs in the United States. After reviewing publicly available information on these potential GSFL manufacturers, DOE determined that 26 were either large manufacturers, manufacturers that were completely foreign owned and operated, or did not sell GSFLs covered by this rulemaking. DOE then contacted the remaining 21 GSFL companies to determine whether they met SBA's definition of a small business and whether they manufactured or sold GSFLs that would be affected by today's proposal. Based on these efforts, DOE estimated that there are 21 small businesses that either manufacture or sell covered GSFLs in the United States.

For IRLs, DOE initially identified a total of 37 potential companies that sell IRLs in the United States. After reviewing publicly available information on these potential IRL manufacturers, DOE determined that 22 were either large manufacturers, manufacturers that were completely foreign owned and operated, or did not sell IRLs covered by this rulemaking. DOE then contacted the remaining 15 IRL companies to determine whether they met SBA's definition of a small business and whether they manufactured or sold IRLs that would be affected by today's proposal. Based on these efforts, DOE estimated that there are 15 small businesses that either manufacture or sell covered IRLs in the United States.

DOE contacted all 21 identified GSFL small businesses to invite them to take part in a small business MIA interview. Of the GSFL manufacturers DOE contacted, eight responded to DOE's email and phone communications and 13 did not. DOE was able to reach and discuss potential standards with two of the eight GSFL small business manufacturers that responded. The remaining six declined DOE's request to be interviewed for this rulemaking. DOE also contacted

all 15 identified IRL small businesses to invite them to take part in a small business MIA interview. Of the IRL manufacturers DOE contacted, five responded to DOE's email and phone communications and 10 did not. DOE was able to reach and discuss potential standards with two of the five IRL small business manufacturers. The remaining three declined DOE's request to be interviewed for this rulemaking. DOE also obtained information about small business manufacturers and potential impacts on small businesses while interviewing large manufacturers.

Three major manufacturers supply approximately 90 percent of the GSFL market. None of these three major GSFL manufacturers are small businesses. DOE estimates that the remaining 10 percent of the GSFL market is served by either small businesses or manufacturers that are completely foreign owned and operated. No small business has more than a three percent market share in the GSFL industry. The same three major GSFL manufacturers also supply approximately 80 percent of the IRL market. Again, none of these three major IRL manufacturers is a small business. DOE estimates that the remaining 20 percent of the IRL market is served by either small businesses or manufacturers that are completely foreign owned and operated. No small business has more than three percent of the IRL market individually. Small businesses that sell covered GSFLs and IRLs tend to be companies that outsource the manufacturing to overseas companies who produce the lamps specified by the small businesses. These small businesses provide the specifications for these lamps and also conduct testing and certification to comply with any U.S. energy conservation standards.

13.6.1.2 Comparison Between Large and Small Entities

For GSFLs and IRLs, small businesses differ from large manufacturers in several ways that directly affect the extent to which a company would be impacted by any potential energy conservation standards. The main differences between small and large entities for this rulemaking are that small manufacturers of GSFLs and IRLs have lower sales volumes and are frequently not the original manufacturers of GSFLs and IRLs. Therefore, these small businesses would not have any capital conversion costs to comply with amended standards, since the machinery used to produce GSFLs and IRLs is owned and operated by overseas manufacturers. The small businesses would most likely experience higher per-unit costs for the products if the conversion costs experienced by the overseas manufacturers are passed through to the small businesses, potentially reducing those small business' manufacturer markups and profits. Small businesses would also have product conversion costs associated with testing and certifying any lamps that would need to be redesigned due to standards. Typically the testing and certification costs are proportional to the number of products offered by a company and not the volume of sales. Some small businesses stated they could offer up to 75 percent of the number of covered products that large manufacturers offer; however, the volume of sales for each single product offered by a small business would be significantly smaller than that of a larger manufacturer. Consequently, the revenue associated with a single product is much smaller for small businesses than for large manufacturers. Therefore, these small businesses could have product conversion costs in the same range as large manufacturers, since product conversion costs scale to number of products offered, even though the total revenue is significantly lower for small businesses compared to large manufacturers.

Lower sales volumes are the biggest disadvantage for most small businesses. A lower-volume business' product conversion costs are spread over fewer units than a larger competitor.

Thus, unless the small business can differentiate its product in some way that earns a price premium, the small business experiences a reduction in profit per-unit relative to the large manufacturer. Most small GSFL and IRL businesses operate in the same lighting markets as large manufacturers and do not operate in niche GSFL and IRL markets. Much of the same equipment would need to be purchased by both large manufacturers and small businesses to produce GSFLs and IRLs at higher efficacy levels. If the small business is not the original lamp manufacturer, the manufacturer that sells to the small business would have to purchase this equipment. Therefore, undifferentiated small businesses would face a greater per-unit cost penalty because they must spread the conversion costs over fewer units. While small businesses may not be directly paying these capital conversion costs, they are still responsible for selling certified products made by the original lamp manufacturers. The costs incurred by contracted manufacturers are passed on to small businesses that must maintain profit margins by either increasing product prices or decreasing profitability.

Small GSFL and IRL businesses will be affected differently by the proposed energy conservation standards compared to large manufacturers. One of the key differences between large manufacturers and the small businesses identified by DOE for this rulemaking is that small IRL and GSFL businesses typically outsource the manufacturing of the lamps they sell to original equipment manufacturers abroad. This, in addition to the small volume of sales typical of small businesses, results in small GSFL and IRL businesses having different types and amounts of conversion costs compared to large manufacturers.

As a result of this rulemaking, small businesses will incur product conversion costs because products that no longer meet the proposed efficacy levels of amended energy conservation standards will most likely need to be redesigned, retested, and recertified. Since small businesses have significantly less revenue and annual R&D budgets than large manufacturers, the product conversion costs necessary to comply with amended standards represent a significant portion of a small business' annual revenue. However, unlike large manufacturers, small businesses will most likely not incur any capital conversion costs due to amended standards because small businesses usually do not own and operate the machinery used to manufacture the covered lamps. The capital conversion costs incurred by original equipment manufacturers will instead be passed along indirectly to the domestic small businesses.

In the GSFL market, DOE identified 21 small GSFL businesses with covered products affected by this rulemaking. It is unlikely that small GSFL businesses will incur any capital conversion costs, since most GSFL small businesses do own and operate the machinery used to manufacture GSFLs; however, they will likely face significant product conversion costs to cover R&D, certification, and testing of products that need to be redesigned to meet the proposed GSFL efficacy levels of today's NOPR. DOE estimates that approximately 20 percent of the covered products offered by small GSFL manufacturers meet the proposed efficacy levels at TSL 5. As a result, an average of approximately 80 percent of products would need to be redesigned to meet proposed efficacy levels, resulting in small GSFL businesses incurring more than \$1.6 million on average in product conversion costs or nearly seven times as much as typical annual GSFL R&D expenses, as shown in Table 13.6.1. GSFL sales account for approximately 25 percent of a typical small business' annual revenue, so redesigning up to 80 percent of those offerings could have a significant impact on their business. Redesigning a large majority of

product offerings that represent a significant revenue stream will be more difficult for small businesses, compared to large businesses, as they have less R&D and revenue.

Table 13.6.1 Estimated GSFL Product Conversion Costs as a Percentage of Annual GSFL R&D Expense

	Product conversion cost as a percentage of annual R&D expense	Total conversion cost as a percentage of annual revenue
Typical Large Manufacturer	1%	0%
Typical Small Manufacturer	692%	31%

In the IRL market, DOE identified 15 small IRL businesses with covered products affected by this rulemaking. DOE estimates that a typical small IRL business will not incur any direct capital conversion costs at TSL 1, the proposed standard in today’s NOPR, since most IRL small businesses do not own and operate the machinery used to manufacture IRLs. The small businesses would most likely experience higher per-unit costs for the products if the conversion costs experienced by the overseas manufacturers are passed through to the small businesses, potentially reducing those small business’ manufacturer markups. However, small IRL businesses are expected to incur product capital conversion costs of approximately \$836 thousand per manufacturer. As Table 13.6.2 below illustrates, small businesses would have significant product conversion costs amounting to nearly nine times the annual amount spent on IRL R&D. Small IRL businesses have much smaller annual R&D budgets as well as smaller annual revenue streams, so incurring the product conversion costs necessary to meet the efficacy standards at TSL 1 could be problematic for those small businesses that have a large majority of their IRLs at the baseline efficacy level. Total conversion cost for a typical small business could amount to nearly a third of small business’ annual IRL revenue.

Table 13.6.2 Estimated IRL Product Conversion Costs as a Percentage of Annual IRL R&D Expense

	Product conversion cost as a percentage of annual R&D expense	Total conversion cost as a percentage of annual revenue
Typical Large Manufacturer	387%	28%
Typical Small Manufacturer	852%	29%

While some small businesses would have some products meet the IRL efficacy levels proposed in today’s NOPR, there are a few small businesses that may not be able to meet the IRL efficacy levels proposed in today’s NOPR. Not meeting TSL 1 for IRL products may also be a strategic decision for some small businesses since IRL products make up about five percent of a typical small IRL business’ revenue. Therefore, some small lighting businesses may choose to not sell IRLs covered by this rulemaking and exit the market.

Small businesses in both the IRL and GSFL industries expressed concern that possible manufacturing downtime, discontinuation of product lines, high direct and indirect conversion costs resulting from amended GSFL and IRL energy conservation standards could have a significant impact on their revenue and could affect domestic employment decisions. Domestic

employment impacts would be especially prevalent in the GSFL market where GSFL revenue accounts for approximately 25 percent of a typical small business' revenue. Domestic employment impacts would be seen in small business' sales forces and warehouse staff that could be potentially downsized as a result of amended GSFL and IRL standards.

13.7 OTHER IMPACTS

13.7.1 Employment

DOE quantitatively assessed the impacts of potential amended energy conservation standards on direct employment. DOE used the GRIM to estimate the domestic labor expenditures and number of domestic production workers in the base case and at each TSL from 2013 to 2046. DOE used statistical data from the U.S. Census Bureau's 2011 Annual Survey of Manufacturers (ASM), the results of the engineering analysis, and interviews with manufacturers to determine the inputs necessary to calculate industry-wide labor expenditures and domestic employment levels. Labor expenditures involved with the manufacture of the product are a function of the labor intensity of the product, the sales volume, and an assumption that wages remain fixed in real terms over time.

In the GRIM, DOE used the labor content of each product and the manufacturing production costs to estimate the annual labor expenditures in the industry. DOE used Census data and interviews with manufacturers to estimate the portion of the total labor expenditures that is attributable to domestic labor.

The production worker estimates in this section cover only workers up to the line-supervisor level directly involved in fabricating and assembling a product within a manufacturing facility. Workers performing services that are closely associated with production operations, such as material handling with a forklift, are also included as production labor. DOE's estimates account for production workers who manufacture only the specific products covered in this rulemaking. For example, a worker on a fluorescent lamp ballast production line would not be included with the estimate of the number of GSFL or IRL workers.

The employment impacts shown in Table 13.7.1 and Table 13.7.2 below represent the potential production employment that could result following amended energy conservation standards. The upper bound of the results estimates the maximum change in the number of production workers that could occur after compliance with amended energy conservation standards, when assuming that manufacturers continue to produce the same scope of covered products in the same production facilities. It also assumes that domestic production does not shift to lower labor-cost countries. Because there is a real risk of manufacturers evaluating sourcing decisions in response to amended energy conservation standards, the lower bound of the employment results includes the estimated total number of U.S. production workers in the industry who could lose their jobs if some or all existing production were moved outside of the United States. While the results present a range of employment impacts following 2017, the sections below also include qualitative discussions of the likelihood of negative employment impacts at the various TSLs. Finally, the employment impacts shown are independent of the employment impacts from the broader U.S. economy, documented in chapter 17 of this NOPR TSD.

13.7.1.1 Employment Impacts for GSFLs

Using 2011 ASM data and interviews with manufacturers, DOE estimates that approximately three quarters of the GSFLs sold in the United States are manufactured domestically. With this assumption, DOE estimates that in the absence of amended energy conservation standards, there would be approximately 1,848 domestic production workers involved in manufacturing GSFLs in 2017. The table below shows the range of the impacts of potential amended energy conservation standards on U.S. production workers in the GSFL industry.

Table 13.7.1 Potential Changes in the Total Number of All Domestic GSFL Production Workers in 2017

	Base Case	Trial Standard Level				
		1	2	3	4	5
Total Number of Domestic Production Workers in 2017 (without changes in production locations)	1,848	1,848	1,847	1,844	1,814	1,817
Potential Changes in Domestic Production Workers in 2017*	-	0	(1)	(4) - (1,848)	(34) - (1,848)	(31) - (1,848)

* DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

At the upper end of the range, all examined TSLs show slight negative impacts on domestic employment levels. DOE believes that manufacturers could face slight negative impacts on domestic employment levels because there would be an increase in the shipments of products typically not manufactured domestically, such as 4-foot T5 MiniBP lamps, and a decrease of products typically manufactured domestically, such as 4-foot MBP lamps.

Several manufacturers emphasized that it is difficult to predict employment impacts of energy conservation standards. One potential uncertainty is the future price of REOs and these employment decisions become more complex when more REOs are required for higher efficacious products.

DOE does not expect any significant changes in domestic employment at TSLs 1 or 2 because standards would not be amended for 4-foot MBP lamps, which comprise approximately 86 percent of GSFL shipments in 2017. While DOE does not anticipate the entire, or even a large portion of, domestic employment to move abroad at TSLs 3, 4 or 5, DOE acknowledges that there could be a loss of domestic employment at these TSLs due to the required increase in efficacy of 4-foot MBP lamps. The potential loss of domestic employment would most likely be a result of a possible increase in the price of REOs. Based on the REO prices modeled in the reference case, DOE does not estimate a significant loss of domestic employment at TSLs 3, 4, or 5. Overall, manufacturers were uncertain about how amended energy conservation standards would affect domestic employment and sourcing decisions. Ultimately, both employment and sourcing decisions could be determined by the stability and predictability of REO prices.

13.7.1.2 Employment Impacts for IRLs

Using 2011 ASM data and interviews with manufacturers, DOE estimates that approximately half of the IRLs sold in the United States are manufactured domestically. With this assumption, DOE estimates that in the absence of amended energy conservation standards, there would be approximately 300 domestic production workers involved in manufacturing IRLs in 2017. The table below shows the range of the impacts of potential amended energy conservation standards on U.S. production workers in the IRL industry.

Table 13.7.2 Potential Changes in the Total Number of Domestic Incandescent Reflector Lamp Production Workers in 2017

	Base Case	Trial Standard Level
		1
Total Number of Domestic Production Workers in 2017 (without changes in production locations)	308	335
Potential Changes in Domestic Production Workers in 2017*	-	27 - (308)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers

At the upper end of the range TSL 1 shows a slight positive impact on domestic employment levels. The increasing product cost at TSL 1 would result in higher labor expenditures per-unit, which could cause manufacturers to hire more domestic workers to meet this added labor demand, assuming IRL production remains in domestic facilities.

Manufacturers are concerned that higher prices for IRLs will drive consumers to alternate technologies and it may not make economic sense for them to continue to produce IRLs. Increasing the efficacy of IRLs would cost manufacturers millions in capital conversion costs. Some stated that they do not have the technology to meet the proposed energy conservation standards and said it is possible they would not spend their limited resources to convert all IRL production to meet efficacy levels at TSL 1. Ultimately, the high costs associated with increasing the efficacy of IRLs could cause some IRL manufacturers to exit the market.

13.7.2 Production Capacity

GSFL manufacturers stated that they did not anticipate any capacity constraints outside of the availability of REOs. One manufacturer pointed out that moving the industry to max-tech efficacy levels could triple the amount of REOs demanded by GSFL manufacturers. Tripling the demand for REOs that are already difficult to come by could trigger some capacity concerns by creating extra volatility in the market. The sharp increase in demand for REOs could cause wide variations in the price and availability of REOs, making production costs more unpredictable.

A few IRL manufacturers expressed concern about the capacity of their infrared (IR) coating machines and that the companies that manufacture those machines might not be able to respond to the demand for IR coating machines necessary to manufacture more efficacious IRLs. DOE, however, received a comment from ADLT, a company that manufactures IR coating machines, that they estimate the current global capacity of IR coatings for IRLs to be over 50 million units annually. This IR coating capacity is supported by three different coating processes

and provided by at least five different companies. ADLT is in a position to increase its IR coating capacity by 20 million units annually using existing equipment within a two-year time period. ADLT believes that additional coating capacity can be generated from one or more of at least five IR coating facilities owned and operated by other companies worldwide. Given a three year period between the ruling and its effective date, ADLT believes there is ample time available for various companies to react to the potential increase in IR coating demand. Given that DOE estimated approximately 65 million IRLs may be sold in 2017 in the preliminary analysis, ADLT believes that IR coating capacity in excess of 70 million units in total can readily be made available. (ADLT, No. 31 at p. 3) This exceeds DOE's NOPR IRL shipment estimate of approximately 32 million units to be sold in 2017. While this exceeds DOE's NOPR IRL shipment estimate of approximately 32 million units to be sold in 2017, ADLT did not provide a source for their claim that the current IR coating capacity is 50 million units annually or for the potential to increase this IR coating capacity to 70 million units annually in 2017. Therefore, it is unclear if this additional IR coating capacity or current IR coating capacity is sufficient to meet the potential U.S. demand for IRLs at the higher EL.

13.7.3 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for some manufacturers, groups of manufacturers, or an industry as a whole. Assessing the impact of a single regulation may overlook the cumulative regulatory burden faced by manufacturers. For this cumulative regulatory burden analysis, DOE examines other significant product-specific regulations that could affect GSFL and IRL manufacturers or their parent companies that will take effect three years before or three years after the effective date of the amended energy conservation standards for GSFLs and IRLs. DOE also describes additional state, Federal, and international regulations with which manufacturers of GSFLs and IRLs must comply.

Companies that produce a wide range of regulated products may be faced with more capital and product conversion costs than their competitors. Additional regulations can prompt those companies to exit the market or reduce their product offerings, potentially reducing overall competition. Companies that could be affected by this rulemaking also typically manufacture high intensity discharge (HID) lamps, metal halide lamp fixtures and ballasts, and fluorescent lamp ballasts, which are also potentially subject to DOE energy conservations. Small businesses in particular may experience greater regulatory impacts due to lower sales volumes over which they must amortize the costs of meeting new regulations. DOE considers a proposed standard not to be economically justified if it contributes to an unacceptable level of cumulative regulatory burden.

13.7.3.1 DOE Regulations for Other Products Produced by GSFL and IRL Manufacturers

In addition to the proposed amended energy conservation standards on GSFLs and IRLs, several other existing and pending Federal regulations may apply to other products produced by GSFL and IRL manufacturers. DOE acknowledges that each regulation can impact a manufacturer's financial operations. Multiple regulations affecting the same manufacturer can quickly strain manufacturers' profit and possibly cause them to exit particular markets. Table

13.7.3 lists the other DOE energy conservation standards that could also affect GSFL and IRL manufacturers in the three years leading up to and after the estimated compliance date of amended energy conservation standards for these products.

Table 13.7.3 Other DOE Regulations Potentially Affecting GSFL and IRL Manufacturers

Regulation	Approximate Compliance Date	Number of Impacted Companies from the Market and Technology Assessment (MTA) (See Chapter 3)	Estimated Industry Total Conversion Expenses
General Service Incandescent Lamps	2012; 2013; & 2014	14	N/A†
Room Air Conditioners	2014	1	\$171 million (2009\$) ^b
Residential Refrigerators and Freezers	2014	1	\$1,243 million (2009\$) ^c
Fluorescent Lamp Ballasts	2014	14	\$82 million (2010\$) ^d
Residential Clothes Dryers	2015	1	\$95 million (2009\$) ^e
Residential Clothes Washers	2015 & 2018	1	\$418.5 million (2010\$) ^f
Residential Water Heaters	2015	1	\$95.9 million (2009\$) ^g
Battery Chargers & External Supplies	2015*	1	N/A††
Electric Motors	2015*	1	N/A††

^b Estimated industry conversion expenses were published in the TSD for the April 2011 room air conditioners direct final rule. 76 FR 22454 The TSD for the 2011 room air conditioners and clothes dryers final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/residential_clothes_dryers_room_ac_direct_final_rule_tsd.html.

^c Estimated industry conversion expenses were published in the TSD for the September 2011 refrigerators, freezers and refrigerator-freezers final rule. 76 FR 57516 The TSD for the 2011 residential refrigerators and freezers final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/refrig_finalrule_tsd.pdf.

^d Estimated industry conversion expenses were published in the TSD for the November 2011 fluorescent lamp ballasts final rule. 76 FR 70548

^e Estimated industry conversion expenses were published in the TSD for the April 2011 residential clothes dryers direct final rule. 76 FR 22454 The TSD for the 2011 fluorescent lamp ballast final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/flb_ecs_finalrule_tsd.pdf.

^f Estimated industry conversion expenses were published in the TSD for the May 2012 residential clothes washers direct final rule. 77 FR 32308 The TSD for the 2012 residential clothes washers direct final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/rcw_direct_final_rule_tsd.html.

^g Estimated industry conversion expenses were published in the TSD for the April 2010 heating products final rule. 75 FR 20112 The TSD for the 2010 heating products final rule can be found at http://www1.eere.energy.gov/buildings/appliance_standards/residential/heating_products_fr_tsd.html.

Regulation	Approximate Compliance Date	Number of Impacted Companies from the Market and Technology Assessment (MTA) (See Chapter 3)	Estimated Industry Total Conversion Expenses
Commercial Distribution Transformers	2016	1	\$61.0 million (2011\$) ^h
Microwave Ovens	2016	1	\$43.1 million (2011\$) ⁱ
Metal Halide Lamp Fixtures	2018*	7	N/A††
HID Lamps	2018*	19	N/A††
Commercial Clothes Washers Update	2018*	1	N/A††
Packaged Terminal Air Conditioners and Heat Pumps (ASHRAE)	2019*	1	N/A††
Commercial Compressors	2019*	1	N/A††
Miscellaneous Residential Refrigeration	2019*	1	N/A††
Single Packaged Vertical Units	2020*	1	N/A††

*The dates listed are an approximation. The exact dates are pending final DOE action.

† For minimum performance requirements prescribed by the Energy Independence and Security Act of 2007 (EISA 2007), DOE did not estimate total industry conversion costs because an MIA was not completed as part of a rulemaking. Pub. L. 110-140. EISA 2007 made numerous amendments to the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 U.S.C. 6291–6309), which established an energy conservation program for major household appliances and industrial and commercial equipment.

†† For energy conservation standards for rulemakings awaiting DOE final action, DOE does not have a finalized estimated total industry conversion cost.

Several manufacturers expressed concern about the proximity between the compliance date of this rulemaking and that of the previous GSFL and IRL rulemaking which was published in July 2009 and became effective in July 2012. (74 FR 34080) GSFL and IRL manufacturers made significant investments to comply with this rulemaking which went into effect in July 2012. IRL manufacturers incurred especially substantial capital costs. Manufacturers stated that complying with the proposed amended standards in this NOPR could cause a large portion of the investments they made to comply with the 2009 Lamps Rule to become stranded. Amended standards could significantly strain the already stretched R&D and capital expenditure budgets these manufacturers have for traditional lighting.

^h Estimated industry conversion expenses were published in the TSD for the April 2013 distribution transformers final rule. 78 FR 23336 The TSD for the 2013 distribution transformers final rule can be found at <http://www.regulations.gov/#!documentDetail;D=EERE-2006-STD-0099-0250>

ⁱ Estimated industry conversion expenses were published in the TSD for the June 2013 microwave ovens final rule. 78 FR 36316 The TSD for the 2013 microwave ovens final rule can be found at <http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0048-0002>

13.7.3.2 Other State and Federal Regulations for Other Products Produced by GSFL and IRL Manufacturers

Energy Independence and Security Act of 2007

The Energy Independence and Security Act of 2007 (EISA 2007) mandated minimum energy conservation standards for general service incandescent lamps (GSILs), expanded the scope of coverage for IRL standards, and mandated reporting requirements for certain lamps. (Pub. L. 110-140) EISA 2007 assigns separate energy conservation standards and minimum rated lifetimes for GSILs and modified spectrum GSILs, with compliance dates ranging from January 1, 2012 to January 1, 2014. The phased-in standards for these lamps are shown in Table 13.7.4 and Table 13.7.5 below.

Table 13.7.4 Energy Conservation Standards for General Service Incandescent Lamps Mandated by EISA 2007

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1,490 – 2,600 lms	72 W	1,000 hours	1/1/2012
1,050-1,489 lms	53 W	1,000 hours	1/1/2013
750-1,049 lms	43 W	1,000 hours	1/1/2014
310-749 lms	29 W	1,000 hours	1/1/2014

Table 13.7.5 Energy Conservation Standards for Modified Spectrum General Service Incandescent Lamps Mandated by EISA 2007

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1,118-1,950 lms	72 W	1,000 hours	1/1/2012
788-1,117 lms	53 W	1,000 hours	1/1/2013
563-787 lms	43 W	1,000 hours	1/1/2014
232-562 lms	29 W	1,000 hours	1/1/2014

Major GSFL and IRL manufacturers are also major manufacturers of GSILs. Consequently, these companies could incur substantial capital and product conversion costs to comply with the GSIL energy conservation standards mandated in EISA 2007. Conversion costs for GSILs may constrain the funds these manufacturers have to spend on R&D, as many of the same engineering resources are used in the development of GSFLs, IRLs, and GSILs. Additionally, the capital costs associated with EISA 2007 compliance may limit the capital available for GSFL and IRL conversion.

EISA 2007 also amended EPCA's definition for IRLs and amended the standard. (42 U.S.C. 6295(i)(1)) Prior to EISA 2007, the statutory definition for IRLs excluded ellipsoidal reflector (ER) shaped, bulge reflector (BR) shaped lamps, and lamps with a diameter less than 2.75 inches. However, EISA 2007 amended this definition to include ER and BR shaped lamps and lamps with diameter greater than 2.25 inches. EISA 2007 also amended 42 U.S.C. 6295(i)(1) to exempt the following lamps from the minimum efficacy requirements: (1) lamps rated at 50 watts or less that are ER30, BR30, BR40, and ER40; (2) lamps rated at 65 watts that are BR30, BR40, or ER40 lamps; and (3) R20 IRLs rated 45 watts or less.

DOE does not have an estimate for the total industry conversion costs that lighting manufacturers have incurred to comply with the EISA 2007 requirements for GSILs and IRLs because an MIA was not completed for the legislatively determined energy conservation standards.

Finally, EISA 2007 requires NEMA to report yearly sales volumes for rough service, vibration service, 2601 – 3300 lumen general service, 3-way, and shatter-resistant lamps from 2010 to 2025. NEMA is required to submit historical shipments for these five types of lamps for DOE to construct a shipment model. The five types of lamps may be regulated by DOE if the actual sales volume of that type of lamp exceeds the volume predicted in DOE's model by 100 percent or more in any given year. (42 U.S.C. 6295(l)(4))

Dodd-Frank Wall Street Reform and Consumer Protection Act (Dodd-Frank Act)

The Dodd-Frank Act mandates that procurement methods and sources of resources that are considered to be conflict minerals be disclosed by manufacturers that are regulated by the SEC. Tungsten is a critical component of IRL filaments and is considered to be a conflict mineral. As a conflict mineral, Tungsten is regulated by the Dodd-Frank Act and represents additional regulation for IRL manufacturers. (HR4173 section 1502)

California Energy Commission Regulation

The California Energy Commission (CEC) requires that manufacturers provide efficacy data on products from a source certified by the CEC. The efficacy data can either be generated by a certified third party or done by the manufacturer itself. In order for a manufacturer to generate efficacy data internally, their testing lab must be certified by the CEC. Data required by the CEC includes lamp power, minimum efficacy, lamp configuration, 1,000 hour lumen maintenance, 40 percent lumen maintenance, rapid cycle stress test, and average rated lamp life.

13.7.3.3 International Regulations for GSFLs and IRLs

US and Canadian Consortium of Gas and Electric Efficiency

The US and Canadian Consortium of Gas and Electric Efficiency (CEE) works with trade associations and government agencies to influence purchases of energy efficient products. CEE has released a reduced wattage specification for T9 fluorescent 25 W and 28 W lamps.

Restriction of Hazardous Substances Directives 1 and 2

According to manufacturers, the Restriction of Hazardous Substance (RoHS) Directive 1 has impacted the way GSFLs are manufactured because of the directive's restrictions on mercury. This regulation bans the sale of new products in the European Union (EU) containing higher than agreed levels of lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyl, and polybrominated diphenyl ether flame retardants. RoHS Directive 2 increased the scope of products regulated by the EU, including IRLs 135 W and below.

Although there is no Federal regulation on RoHS, California has passed SB 20: Electronic Waste Recycling Act of 2003. Under this law, California limits the amount of

hazardous substances included in the RoHS directive that can be sold in California. With the exception of some IRL products, manufacturers do not anticipate RoHS will significantly impact the GSFL or IRL industries as a whole. According to manufacturers, the industry has already lowered mercury and lead levels to below RoHS specifications.

Saudi Arabian Standards Organization (SASO)

The SASO requires that manufacturers obtain a Certification of Conformity (CoC) by having their products tested by a third party in order to be cleared to be exported to Saudi Arabia. Once a CoC is obtained, SASO then performs their own testing and self approves products for exportation to Saudi Arabia.

Natural Resources Canada Office of Energy Efficiency

Natural Resources Canada (NRCAN) Office of Energy Efficiency (OEE) published amendment 11 to Canada's *Energy Efficiency Regulations* for IRL standards. The amendment modifies the definition of and expands the scope of IRLs, modifies the number of exempted IRLs, harmonizes IRL standards with EISA 2007.

Norma Oficial Mexicana

Norma Oficial Mexicana (NOM) mandates that all electrical products receive an NOM certification and meet Mexican energy efficiency standards. NOM-0028 specifies energy efficiency standards and acceptable test methods for general purpose lamps. The scope of NOM-028 includes GSFLs and IRLs.

Ecodesign

Directive 2009/125/EC or European "Ecodesign" requirements state that manufacturers must meet "harmonized" or similar energy efficiency requirements set by its members. Ecodesign also requires products that meet Ecodesign standards be labeled with the designated European Conformity "CE" logo. Efficiency standards associated with the directive are still being set.

Minamata Convention on Mercury

The Minamata Convention on Mercury limits the mercury content in manufactured products. In accordance with Article 4, paragraph 2, of the Minamata Convention on Mercury, the United States limits the mercury content of all manufactured products, including GSFLs.

13.7.3.4 Product Labeling Regulations

Manufacturers must comply with product labeling mandated by both the Interstate Mercury Education and Reduction Clearinghouse (IMERC) and the Federal Trade Commission (FTC).

Interstate Mercury Education and Reduction Clearinghouse

IMERC supports legislation that lowers allowable mercury levels in certain products and seeks to eliminate certain products in participating states. GSFL manufacturers stated in manufacturer interviews that IMERC's labeling requirements have increased labeling costs for GSFLs. IMERC members include California, Connecticut, Illinois, Louisiana, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, Vermont, and Washington.

Federal Trade Commission Energy Labeling Rule

FTC requires that all lamps sold in the United States have a "Lighting Facts" label informing consumers of a lamp's light output, annual energy cost, life, color temperature, wattage, and design voltage.

13.8 CONCLUSION

The following section summarizes the impacts for the scenarios DOE believes are most likely to capture the range of impacts on GSFL and IRL manufacturers as a result of amended energy conservation standards. DOE also notes that while these scenarios bound the range of most plausible impacts on manufacturers, there potentially could be circumstances that cause manufacturers to experience impacts outside of this range.

13.8.1 GSFL Impacts

TSL 1 sets the efficacy level at baseline for two product classes (4-foot MBP and 8-foot SP slimline) and EL 1 for three product classes (8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO). EL 1 for the 4-foot T5 MiniBP HO product class represents the maximum technology efficacy level. At TSL 1, DOE estimates impacts on INPV range from \$41.8 million to -\$0.9 million, or a change in INPV of 2.7 percent to -0.1 percent. At TSL 1, industry free cash flow (operating cash flow minus capital expenditures) is estimated to decrease by approximately 0.5 percent to \$156.9 million, compared to the base case value of \$157.7 million in 2016, the year leading up to proposed energy conservation standards.

Percentage impacts on INPV are slightly positive to slightly negative at TSL 1. DOE does not anticipate that manufacturers would lose a significant portion of their INPV at this TSL. This is because the vast majority of shipments already meets or exceeds the efficacy levels prescribed at TSL 1. DOE projects that in the excepted year of compliance (2017), 100 percent of 4-foot MBP and 8-foot SP slimline shipments would meet or exceed the efficacy levels at TSL 1. DOE estimates that these lamps account for 88 percent of GSFL shipments in the 2017. Meanwhile, in 2017, 33 percent of 8-foot RDC HO shipments, 45 percent of 4-foot T5 MiniBP SO, and 37 percent of 4-foot T5 MiniBP HO shipments would meet the efficacy levels at TSL 1. Because these products comprise a very small percentage of total GSFL shipments in 2017, a very small percentage of total GSFL shipments would need to be converted at TSL 1 to meet these efficacy standards.

DOE expects conversion costs to be small compared to the industry value because most of the GSFL shipments, on a total volume basis, already meet or exceed the efficacy levels analyzed at this TSL. DOE expects GSFL manufacturers to incur \$0.9 million in product

conversion costs for lamp redesign and testing. DOE estimates manufacturers will have minimal capital conversion costs associated with TSL 1, as most efficacy gains will be achieved through increasing the amount of REOs used to coat the lamps, not through any major equipment upgrades or capital investments. DOE expects \$1 million in capital conversion costs for manufacturers to upgrade and recalibrate production line automation.

At TSL 1, under the flat markup scenario, the shipment-weighted average MPC increases by approximately 5 percent relative to the base case MPC. Manufacturers are able to fully pass on this cost increase to consumers by design in this markup scenario. This slight price increase would mitigate the \$1.9 million in conversion costs estimated at TSL 1, resulting in slightly positive INPV impacts at TSL 1 under the flat markup scenario.

Under the preservation of operating profit markup scenario, manufacturers earn the same operating profit as would be earned in the base case, but manufacturers do not earn additional profit from their investments. The 5 percent MPC increase is slightly outweighed by a lower average markup of 1.51 (compared to the flat markup of 1.52) and \$1.9 million in conversion costs, resulting in small negative impacts at TSL 1.

TSL 2 sets the efficacy level at baseline for one product class (4-foot MBP), EL 1 for three product classes (8-foot SP slimline, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO), and EL 2 for one product class (8-foot RDC HO). EL 1 for the 4-foot T5 MiniBP HO product class and EL 2 for the 8-foot RDC HO product class represent the maximum technology efficacy levels. At TSL 2, DOE estimates impacts on INPV to range from \$37.8 million to -\$9.2 million, or a change in INPV of 2.5 percent to -0.6 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 4 percent to \$152.1 million, compared to the base case value of \$157.7 million in 2016.

Percentage impacts on INPV are slightly positive to slightly negative at TSL 2. DOE does not anticipate that manufacturers would lose a significant portion of their INPV at this TSL because the vast majority of shipments already meets or exceeds the efficacy levels prescribed at TSL 2. DOE projects that in 2017, 100 percent of 4-foot MBP shipments would meet or exceed the efficacy levels at TSL 2. DOE estimates that shipments of this product classes will comprise 86 percent of GSFL shipments in 2017. Meanwhile, in 2017, 57 percent of 8-foot SP slimline lamps shipments, 10 percent of 8-foot RDC HO shipments, 45 percent of 4-foot T5 MiniBP SO, and 37 percent of 4-foot T5 MiniBP HO shipments would meet or exceed the efficacy levels at TSL 2.

DOE expects conversion costs to be small compared to the industry value because most of the GSFL shipments, on a total volume basis, already meet or exceed the efficacy levels analyzed at this TSL. DOE expects that product conversion costs will rise from \$0.9 million at TSL 1 to \$2.0 million at TSL 2 for lamp redesign and testing. Capital conversion costs will increase from \$1.0 million at TSL 1 to \$11.0 million at TSL 2. This is driven by the fact that both 8-foot product classes would have to meet higher efficacy levels at this TSL. DOE believes this will result in higher capital conversion costs related to upgrading and recalibrating production line automation.

At TSL 2, under the flat markup scenario, the shipment-weighted average MPC increases by 5 percent relative to the base case MPC. In this scenario, INPV impacts are slightly positive because of manufacturers' ability to pass the higher production costs to consumers outweighs the \$13.0 million in conversion costs. Under the preservation of operating profit markup scenario, the 5 percent MPC increase is slightly outweighed by a lower average markup of 1.51 (compared to the flat markup of 1.52) and \$13.0 million in conversion costs, resulting in slightly negative impacts at TSL 2.

TSL 3 sets the efficacy level at baseline for one product class (8-foot SP slimline) and EL 1 for four product classes (4-foot MBP 8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO). EL 1 for the 4-foot T5 MiniBP HO product class represents the maximum technology efficacy level. At TSL 3, DOE estimates impacts on INPV to range from \$120.5 million to -\$11.5 million, or a change in INPV of 7.8 percent to -0.7 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 2 percent to \$154.7 million, compared to the base case value of \$157.7 million in 2016.

While more significant than the impacts at TSL 2, the impacts on INPV at TSL 3 are still relatively minor compared to the total industry value. Percentage impacts on INPV are slightly positive to slightly negative at TSL 3. DOE does not anticipate that manufacturers would lose a significant portion of their INPV at TSL 3. While less than the previous TSLs, a large percentage of total shipments still already meet or exceed the efficacy levels prescribed at TSL 3. DOE projects that in 2016, 56 percent of the 4-foot MBP, 100 percent of 8-foot SP slimline, 33 percent of 8-foot RDC HO shipments, 45 percent of 4-foot T5 MiniBP SO, and 37 percent of 4-foot T5 MiniBP HO shipments would meet or exceed the efficacy levels at TSL 3.

DOE expects conversion costs to remain small at TSL 3 compared to the industry value because a significant percentage of the GSFL shipments, on a total volume basis, already meet or exceed the efficacy levels proposed at this TSL. TSL 3 is the first TSL that increases the efficacy requirement for 4-foot MBP, which as previously noted, comprise a large majority of GSFL shipments. Efficacy gains for these products, however, would likely be achieved with additional REOs, which would not require any significant capital investments. At TSL 3, DOE expects product conversion costs to increase from TSL 2 to \$5.3 million. DOE, however, estimates that capital conversion costs will decrease from TSL 2 to \$3.0 million at TSL 3 since no amended efficacy standards would be set at TSL 3 for 8-foot SP slimline products and the 8-foot RDC HO product class has a lower EL at TSL 3 than at TSL 2. The lower ELs for these two product classes outweigh the increase in EL of the 4-ft MBP product class and would cause manufacturers to invest less in capital conversion costs at TSL 3 than at TSL 2.

At TSL 3, under the flat markup scenario, the shipment-weighted average MPC increases by 16 percent relative to the base case MPC. In this scenario, INPV impacts are slightly positive because manufacturers' ability to pass the higher production costs to consumers outweighs the \$8.3 million in conversion costs. Under the preservation of operating profit markup scenario, the 16 percent MPC increase is slightly outweighed by a lower average markup of 1.51 (compared to the flat markup scenario markup of 1.52) and \$8.3 million in conversion costs, resulting in negative impacts at TSL 3.

TSL 4 sets the efficacy level at baseline for one product class (8-foot SP slimline), EL 1 for three product classes (8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO), and EL 2 for one product class (4-foot MBP). EL 1 for the 4-foot T5 MiniBP HO product class and EL 2 for the 4-foot MBP product class represent the maximum technology efficacy levels. At TSL 4, DOE estimates impacts on INPV to range from \$358.5 million to -\$22.9 million, or a change in INPV of 23.2 percent to -1.5 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 3 percent to \$152.9 million, compared to the base case value of \$157.7 million in the year leading up to energy conservation standards.

Percentage impacts on INPV are moderately positive to slightly negative at TSL 4. DOE projects that in 2017, 21 percent of 4-foot MBP, 100 percent of 8-foot SP slimline, 33 percent of 8-foot RDC HO shipments, 45 percent of 4-foot T5 MiniBP SO, and 37 percent of 4-foot T5 MiniBP HO shipments would meet or exceed the efficacy levels at TSL 4.

While DOE expects conversion costs to increase from TSL 3 to TSL 4, DOE estimates the costs will still be small compared to the total industry value. DOE expects product conversion costs for GSFL manufacturers to increase from \$5.3 million at TSL 3 to \$7.5 million at TSL 4. DOE expects capital conversion costs to increase from \$3.0 million at TSL 3 to \$5.5 million at TSL 4. While a higher percentage of shipments would need to be converted to meet the efficacy requirements at TSL 4, increasing the efficacy of GSFLs will not likely be a very capital-intensive process. Instead, increasing GSFL efficacy will likely be more focused around increasing the amount of REOs in the lamps.

At TSL 4, under the flat markup scenario the shipment-weighted average MPC increases by 52 percent relative to the base case MPC. In this scenario, INPV impacts are slightly positive because of manufacturers' ability to pass the higher production costs to consumers outweighs the \$13.0 million in conversion costs. Under the preservation of operating profit markup scenario, the 52 percent MPC increase is slightly outweighed by a lower average markup of 1.51 (compared to the flat markup scenario markup of 1.52) and \$13.0 million in conversion costs, resulting in negative impacts at TSL 4.

TSL 5 sets the efficacy level at the maximum technology for all product classes. This represents EL 1 for one product class (4-foot T5 MiniBP HO) and EL 2 for five product classes (4-foot MBP, 8-foot SP slimline, 8-foot RDC HO, and 4-foot T5 MiniBP SO). At TSL 5, DOE estimates impacts on INPV to range from \$397.1 million to -\$39.9 million, or a change in INPV of 25.7 percent to -2.6 percent. At this proposed level, industry free cash flow is estimated to decrease by approximately 10 percent to \$143.4 million, compared to the base case value of \$157.7 million in 2016.

Percentage impacts on INPV are significantly positive to slightly negative at TSL 5. DOE projects that in 2017, 21 percent of the 4-foot MBP, 25 percent of 8-foot SP slimline, 10 percent of 8-foot RDC HO shipments, 14 percent of 4-foot T5 MiniBP SO, and 37 percent of 4-foot T5 MiniBP HO shipments would meet the efficacy levels at TSL 5.

DOE expects conversion costs to significantly increase from TSL 4 to TSL 5 due to the 8-foot SP slimline, 8-foot RDC HO, and 4-foot T5 MiniBP HO product classes moving to max-

tech ELs at TSL 5. However, these larger total conversion costs at TSL 5, \$38.6 million, remain relatively small compared to the almost \$2 billion total GSFL industry value at TSL 5. DOE expects GSFL manufacturers to incur \$9.1 million in product conversion costs for lamp redesigns and testing. DOE estimates that capital conversion costs will increase more substantially to \$29.5 million at TSL 5. This is a result of manufacturers having to upgrade all of their production lines to manufacture max-tech products.

At TSL 5, under the flat markup scenario, the shipment-weighted average MPC increases by 57 percent relative to the base case MPC. In this scenario, INPV impacts are slightly positive because of manufacturers' ability to pass the higher production costs to consumers outweighs the \$38.6 million in conversion costs. Under the preservation of operating profit markup scenario, the 57 percent MPC increase is slightly outweighed by a lower average markup of 1.51 (compared to the flat markup scenario markup of 1.52) and \$38.6 million in conversion costs, resulting in negative impacts at TSL 5.

13.8.2 IRL Impacts

TSL 1 sets the efficacy level at EL 1, the max tech level, for the IRL representative product class. At TSL 1, DOE estimates impacts on INPV to range from -\$47.5 million to -\$51.8 million, or a change in INPV of -27.0 percent to -29.5 percent. At TSL 1, industry free cash flow is estimated to decrease by approximately 131 percent to -7.5 million, compared to the base case value of \$23.8 million in 2016.

INPV impacts are significantly negative at TSL 1 regardless of the markup scenario chosen. DOE estimates that in 2017, 41 percent of IRL shipments would meet the efficacy requirements proposed at TSL 1. The majority of shipments would need to be converted to meet the standards proposed at this TSL.

DOE expects substantial conversion costs for IRL manufacturers at TSL 1 associated with increasing the efficacy of IRLs. Manufacturers would have to invest in retooling burner machines, increasing coating capacity, and upgrading their production lines to allow for enhanced reflector coating. Some manufacturers expressed concern that they do not currently possess the technology required at the analyzed standard level and could exit the market entirely. Overall, DOE expects these capital conversion costs to total \$65.4 million for the industry. DOE estimates that IRL manufacturers will also incur \$6.1 million in product conversion costs for lamp and production line redesign, as well as testing and certification.

At TSL 1, under the flat markup scenario, the shipment-weighted average MPC increases by 13 percent relative to the base case MPC. In this scenario, INPV impacts are negative because the manufacturers' ability to pass the higher production costs to consumers does not outweigh \$71.5 million in conversion costs. Under the preservation of operating profit markup scenario, the 13 percent MPC increase is outweighed by a lower average markup of 1.50 (compared to the flat markup scenario markup of 1.52) and \$71.5 million in conversion costs, resulting in negative impacts at TSL 1.

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¹ Securities and Exchange Commission, Annual 10-K Reports, Various Years, Washington DC. <www.sec.gov>.

² Standard and Poors Financial Services LLC, Company Credit Ratings, Various Companies, New York, NY. <www2.standardandpoors.com>.

³ NEMA – NEMA Members. Last Accessed June 5, 2013. <www.nema.org/about/members/>.

⁴ McKinsey & Company, Inc. *Valuation: Measuring and Managing the Value of Companies*, 3rd Edition, Copeland, Koller, Murrin. New York: John Wiley & Sons, 2000.

CHAPTER 14. EMISSIONS IMPACT ANALYSIS

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CHAPTER 14. EMISSIONS IMPACT ANALYSIS

14.1 INTRODUCTION

The emissions analysis consists of two components. The first component estimates the effect of potential energy conservation standards on power sector emissions of carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfur dioxide (SO₂) and mercury (Hg). The second component estimates the impacts of a potential standard on emissions of two additional greenhouse gases, methane (CH₄) and nitrous oxide (N₂O), as well as the reductions to emissions of all species due to “upstream” activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions. Together, these emissions account for the full-fuel-cycle (FFC), in accordance with DOE’s FFC Statement of Policy. 76 FR 51282 (Aug. 18, 2011).

The analysis of most power sector emissions uses marginal emissions intensity factors derived from runs of DOE’s NEMS-BT model, described in Chapter 16. DOE used the version of NEMS based on the *Annual Energy Outlook 2013 (AEO 2013)*.¹ Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. *AEO 2013* generally represents current Federal and State legislation and final implementation regulations in place as of the end of December 2012. Where applicable, site emissions of CO₂ and NO_x are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).²

Combustion emissions of CH₄ and N₂O (from power plants and from upstream combustion) are estimated using emissions intensity factors published by the EPA, GHG Emissions Factors Hub.^a

The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).³ The upstream emissions include emissions from fuel combustion during extraction, processing and transportation of fuel, and “fugitive” emissions (direct leakage to the atmosphere) of CH₄ and CO₂.

The emissions intensity factors are expressed in terms of physical units per MWh or MMBtu of site energy savings. Total emissions reductions are estimated using the energy savings calculated in the national impact analysis (chapter 12).

For CH₄ and N₂O, DOE also presents results in terms of units of carbon dioxide equivalent (CO₂e). Gases are converted to CO₂e by multiplying by the gas’ global warming potential (GWP) over a 100 year time horizon. Based on the Fourth Assessment Report of the

^a <http://www.epa.gov/climateleadership/guidance/ghg-emissions.html>

Intergovernmental Panel on Climate Change,^b DOE used GWP values of 25 for CH₄ and 298 for N₂O.

14.2 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

SO₂ emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO₂ for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO₂ emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit) but parts of it remained in effect. On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR. See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012). The court ordered EPA to continue administering CAIR. The *AEO 2013* emissions factors used for this analysis assume that CAIR remains a binding regulation through 2040.

The attainment of emissions caps is typically flexible among affected Electric Generating Units (EGUs) and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO₂ emissions allowances resulting from the lower electricity demand caused by the imposition of an efficiency standard could be used to permit offsetting increases in SO₂ emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO₂ emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO₂ as a result of standards.

Beginning in 2015, however, SO₂ emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants, which were announced by EPA on December 21, 2011. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO₂ (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO₂ emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2013* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2015. Both technologies, which are used to reduce acid gas emissions, also reduce SO₂ emissions. Under the MATS, NEMS shows a reduction in SO₂

^b Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland. 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, Editors. 2007. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. p. 212.

emissions when electricity demand decreases (e.g., as a result of energy efficiency standards). Emissions will be far below the cap established by CAIR, so it is unlikely that excess SO₂ emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO₂ emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO₂ emissions in 2015 and beyond.

CAIR established a cap on NO_x emissions in 28 eastern States and the District of Columbia. Energy conservation standards are expected to have little effect on NO_x emissions in those States covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by CAIR, so DOE estimated NO_x emissions reductions from potential standards for those States.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. DOE estimated mercury emissions reductions using the NEMS-BT based on *AEO 2013*, which incorporates the MATS.

14.3 POWER SECTOR EMISSIONS FACTORS

The analysis of power sector emissions uses marginal emissions intensity factors derived from runs of DOE's NEMS-BT model, using the version updated to the *Annual Energy Outlook 2013 (AEO 2013)*. To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity, fuel use and power sector emissions. A marginal emissions intensity factor is defined by dividing the reduction in the total emissions of a given pollutant by the reduction in total generation (in billion kWh). DOE uses the site energy savings multiplied by a T&D loss factor to estimate the reduction in generation for each TSL. Details on the approach used may be found in Coughlin (2013).³

Table 14.3.1 and Table 14.3.2 present the power plant emissions factors for selected years. These power plant emissions factors are derived from the emissions factors of the plant types used to supply electricity for either commercial or residential lighting. The average factors for each year take into account the projected shares of each of the sources in total electricity generation. The marginal calculation based on the NEMS-BT model accounts for the fact that NO_x emissions are capped in some States.

Table 14.3.1 Power Plant Emissions Factors for Residential Lighting End Use*

	Unit**	2016	2020	2025	2030	2035	2040
CO ₂	kg/MWh	601.1	601.1	565.3	535.7	491.4	335.2
SO ₂	g/MWh	395.8	395.8	563.7	699.4	270.2	339.0
NO _x	g/MWh	332.8	332.8	292.4	247.5	-113.8	-22.3
Hg	g/MWh	0.00143	0.00143	0.00050	0.00095	0.00059	0.00057
N ₂ O	g/MWh	6.9	7.2	7.2	7.1	7.1	6.9
CH ₄	g/MWh	48.3	50.2	50.1	49.6	49.2	47.8

** Refers to MWh of site electricity savings.

Table 14.3.2 Power Plant Emissions Factors for Commercial Lighting End Use*

	Unit**	2016	2020	2025	2030	2035	2040
CO ₂	kg/MWh	664.1	664.1	615.7	578.9	529.3	458.8
SO ₂	g/MWh	663.7	663.7	802.0	854.0	632.4	843.2
NO _x	g/MWh	391.0	391.0	362.3	287.9	216.4	213.6
Hg	g/MWh	0.00165	0.00165	0.00071	0.00112	0.00088	0.00100
N ₂ O	g/MWh	6.9	7.2	7.2	7.1	7.1	6.9
CH ₄	g/MWh	48.3	50.2	50.1	49.6	49.2	47.8

** Refers to MWh of site electricity savings.

14.4 UPSTREAM FACTORS

The upstream emissions accounting uses the same approach as the upstream energy accounting described in appendix 10-A. See also Coughlin (2013).³ When demand for a particular fuel is reduced, there is a corresponding reduction in the emissions from combustion of that fuel at either the building site or the power plant. The associated reduction in energy use for upstream activities leads to further reductions in emissions. These upstream emissions are defined to include the combustion emissions from the fuel used upstream, the fugitive emissions associated with the fuel used upstream, and the fugitive emissions associated with the fuel used on site.

Fugitive emissions of CO₂ occur during oil and gas production, but are small relative to combustion emissions. They comprise about 2.5% of total CO₂ emissions for natural gas and 1.7% for petroleum fuels. Fugitive emissions of methane occur during oil, gas and coal production. Combustion emissions of CH₄ are very small, while fugitive emissions (particularly for gas production) may be relatively large. Hence, fugitive emissions make up over 99% of total methane emissions for natural gas, about 95% for coal, and 93% for petroleum fuels.

Upstream emissions factors account for both fugitive emissions and combustion emissions in extraction, processing, and transport of primary fuels. For ease of application in its

analysis, DOE developed all of the emissions factors using site (point of use) energy savings in the denominator. Table 14.4.1 presents the electricity upstream emissions factors for selected years. The caps that apply to power sector NO_x emissions do not apply to upstream combustion sources.

Table 14.4.1 Electricity Upstream Emissions Factors

	Unit*	2015	2020	2025	2030	2035	2040
CO ₂	kg/MWh	28.5	27.3	26.9	26.8	26.9	26.3
SO ₂	g/MWh	4.9	5.3	5.3	5.2	5.2	5.1
NO _x	g/MWh	361	340	334	333	336	329
Hg	g/MWh	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
N ₂ O	g/MWh	0.25	0.25	0.25	0.25	0.24	0.24
CH ₄	g/MWh	2142	2025	2008	2025	2057	1999

* Refers to MWh of site electricity savings.

14.5 EMISSIONS IMPACT RESULTS

Table 14.5.1 and Table 14.5.2 present the estimated cumulative emissions reductions for the lifetime of GSFLs and IRLs sold in 2017-2046 for each TSL.

Table 14.5.1 Cumulative Emissions Reduction for GSFL Trial Standard Levels

	Trial Standard Level				
	1	2	3	4	5
Power Sector Emissions					
CO ₂ (million metric tons)	9.85	9.68	41.8	140	160
SO ₂ (thousand tons)	15.1	14.8	64.3	219	250
NO _x (thousand tons)	5.54	5.47	23.4	77.5	88.7
Hg (tons)	0.019	0.019	0.082	0.279	0.318
N ₂ O (thousand tons)	0.160	0.156	0.688	2.38	2.69
CH ₄ (thousand tons)	1.07	1.04	4.55	15.5	17.6
Upstream Emissions					
CO ₂ (million metric tons)	0.522	0.511	2.22	7.56	8.61
SO ₂ (thousand tons)	0.112	0.110	0.478	1.62	1.85
NO _x (thousand tons)	7.17	7.02	30.5	104	118
Hg (tons)	0.000	0.000	0.001	0.004	0.005
N ₂ O (thousand tons)	0.005	0.005	0.023	0.077	0.088
CH ₄ (thousand tons)	43.3	42.4	185	628	716
Total Emissions					
CO ₂ (million metric tons)	10.4	10.2	44.0	148	169
SO ₂ (thousand tons)	15.2	14.9	64.8	221	252
NO _x (thousand tons)	12.7	12.5	53.9	181	207
Hg (tons)	0.020	0.019	0.083	0.283	0.323
N ₂ O (thousand tons)	0.165	0.161	0.710	2.45	2.78
N ₂ O (thousand tons CO ₂ eq)	49.2	48.0	212	731	827
CH ₄ (thousand tons)	44.4	43.4	189	643	733
CH ₄ (thousand tons CO ₂ eq)	1,109	1,086	4,726	16,087	18,331

Table 14.5.2 Cumulative Emissions Reduction for IRL Trial Standard Level

	Trial Standard Level
	1
Power Sector Emissions	
CO ₂ (million metric tons)	0.663
SO ₂ (thousand tons)	0.686
NO _x (thousand tons)	0.345
Hg (tons)	0.001
N ₂ O (thousand tons)	0.010
CH ₄ (thousand tons)	0.066
Upstream Emissions	
CO ₂ (million metric tons)	0.032
SO ₂ (thousand tons)	0.007
NO _x (thousand tons)	0.445
Hg (tons)	0.000
N ₂ O (thousand tons)	0.000
CH ₄ (thousand tons)	2.66
Total Emissions	
CO ₂ (million metric tons)	0.696
SO ₂ (thousand tons)	0.693
NO _x (thousand tons)	0.790
Hg (tons)	0.001
N ₂ O (thousand tons)	0.010
N ₂ O (thousand tons CO ₂ eq)	2.94
CH ₄ (thousand tons)	2.73
CH ₄ (thousand tons CO ₂ eq)	68.2

Figure 14.5.1 through Figure 14.5.12 show the annual reductions for GSFL and IRL emissions for each type of emission from each TSL. The reductions reflect the lifetime impacts of equipment sold in 2017-2046.

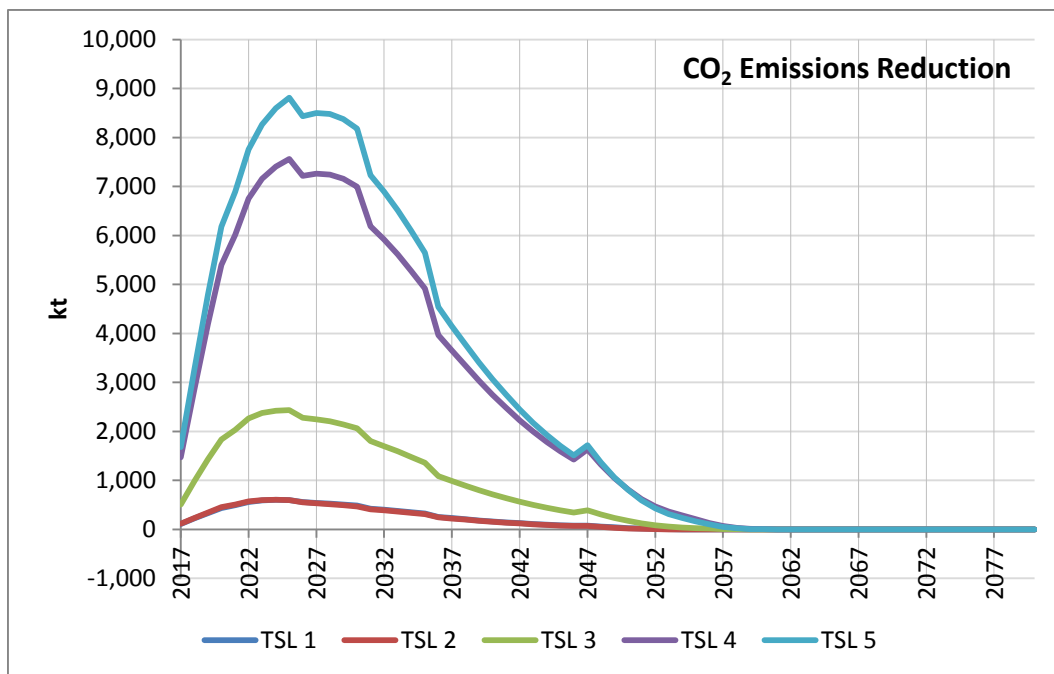


Figure 14.5.1 CO2 Total Emissions Reduction for GSFLs

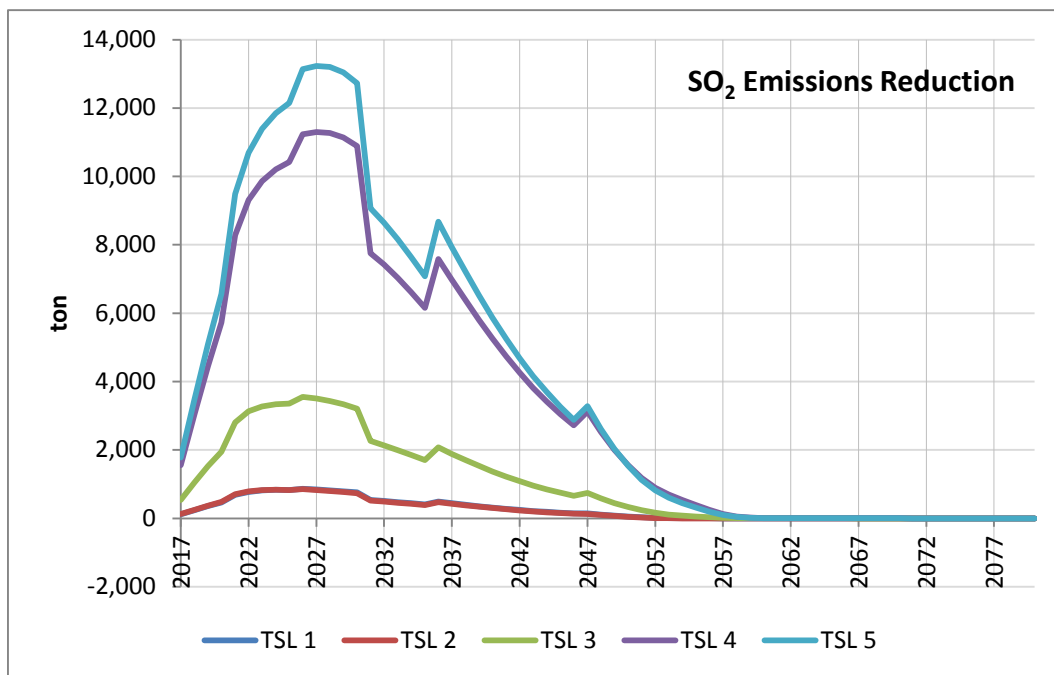


Figure 14.5.2 SO2 Total Emissions Reduction for GSFLs

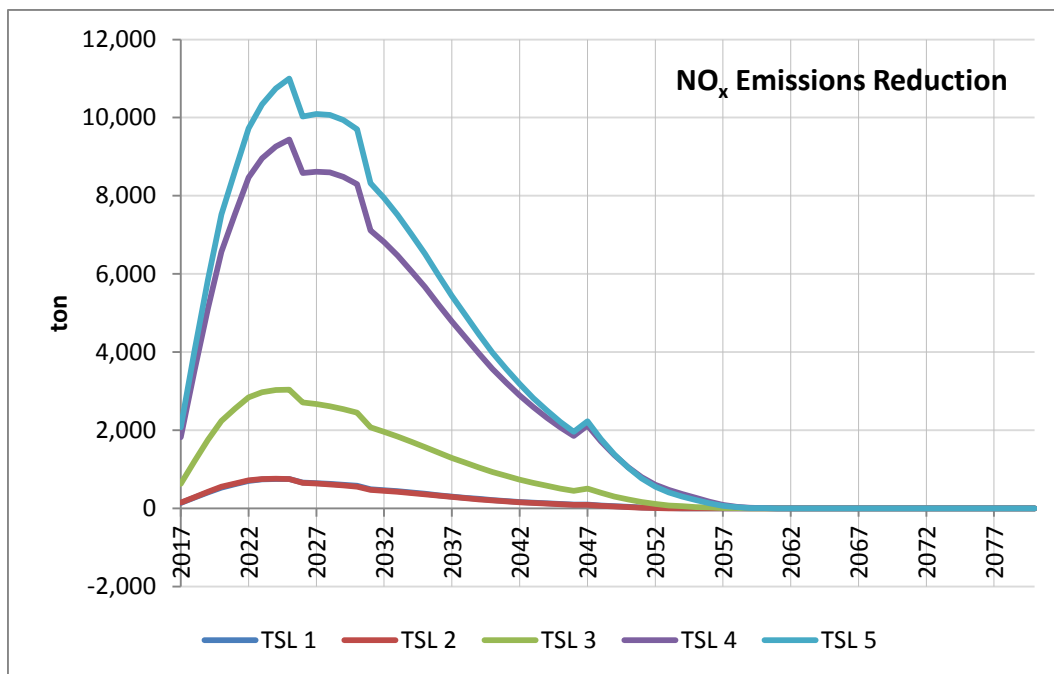


Figure 14.5.3 NO_x Total Emissions Reduction for GSFLs

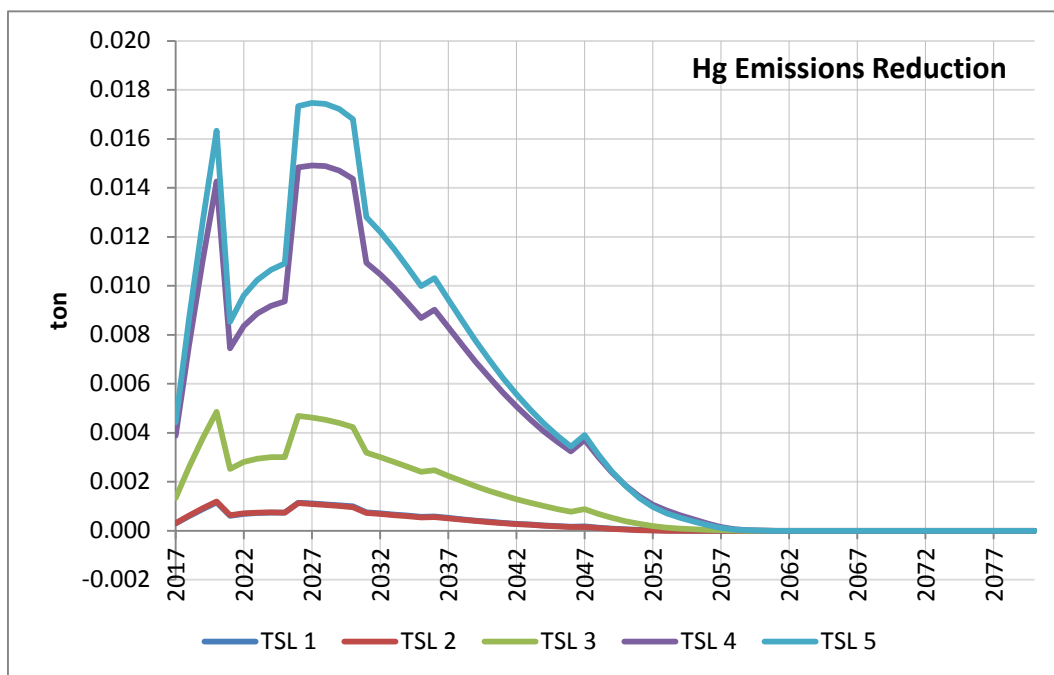


Figure 14.5.4 Hg Total Emissions Reduction for GSFLs

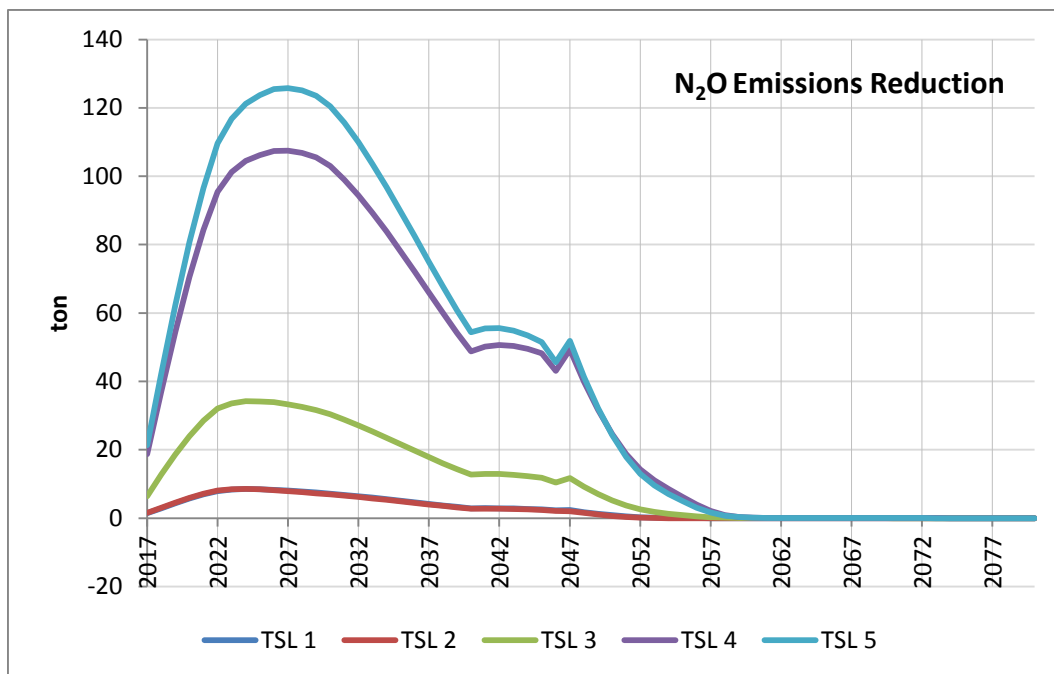


Figure 14.5.5 N₂O Total Emissions Reduction for GSFLs

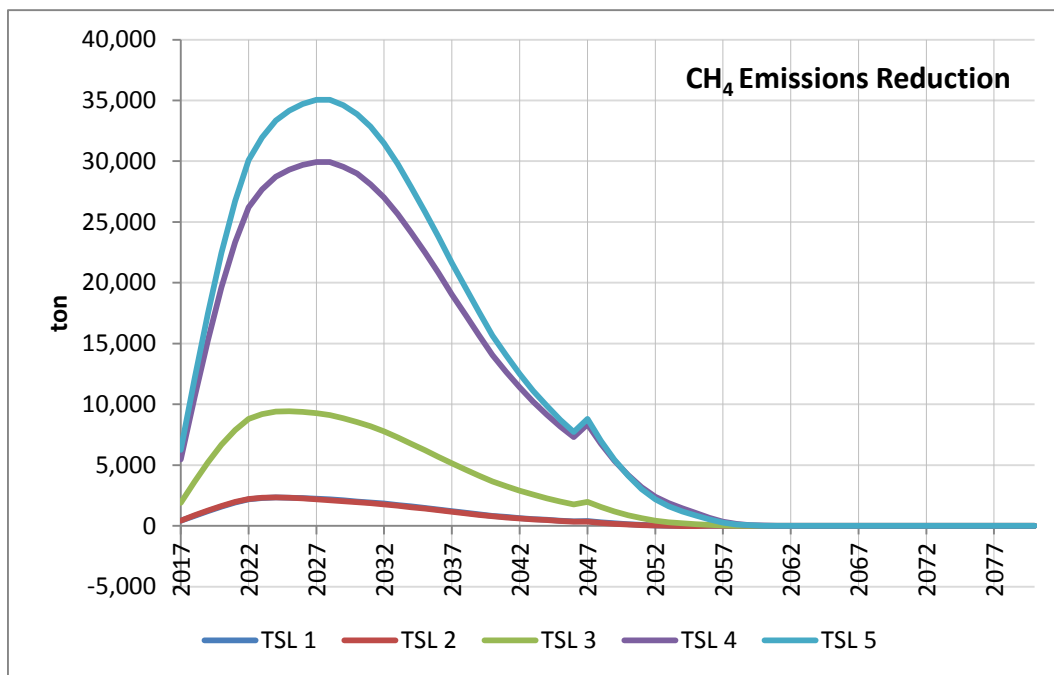


Figure 14.5.6 CH₄ Total Emissions Reduction for GSFLs

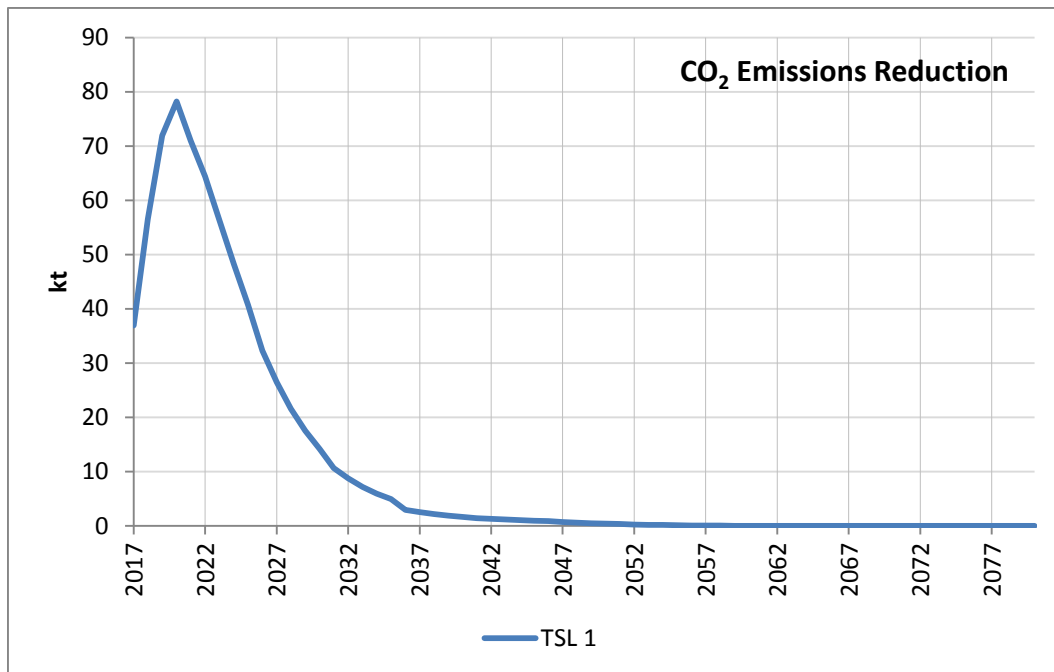


Figure 14.5.7 CO₂ Total Emissions Reduction for IRLs

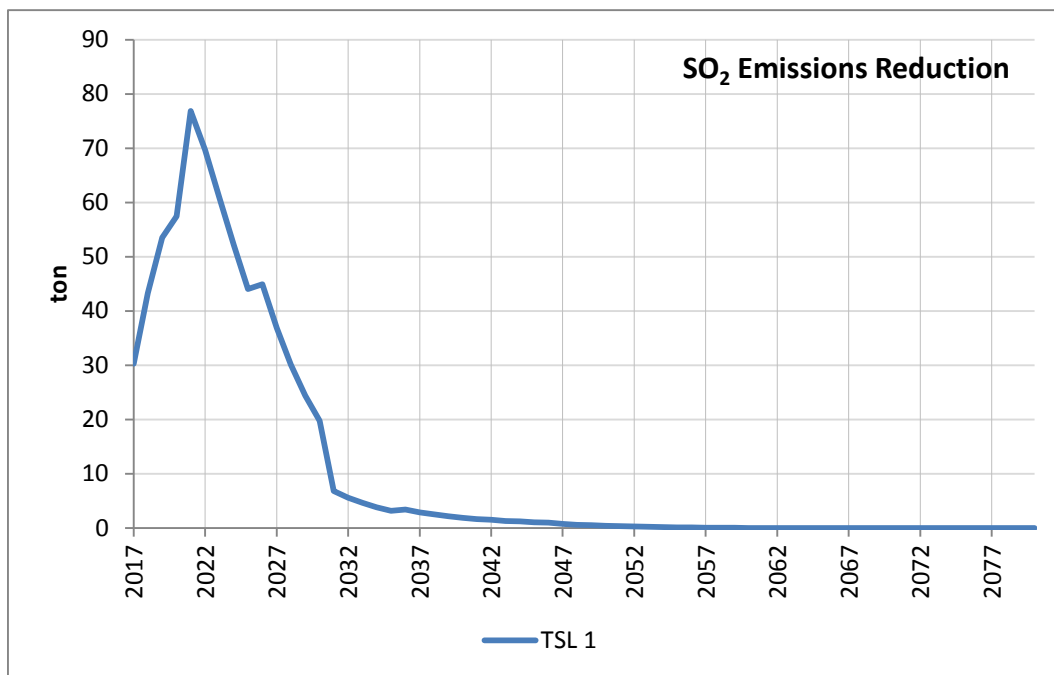


Figure 14.5.8 SO₂ Total Emissions Reduction for IRLs

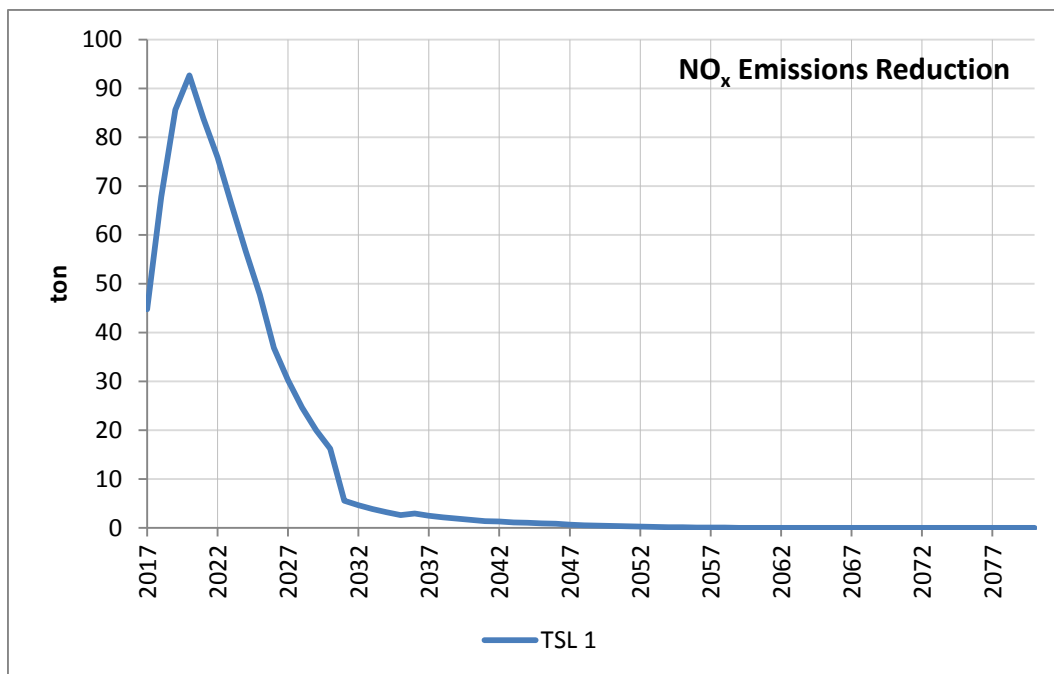


Figure 14.5.9 NO_x Total Emissions Reduction for IRLs

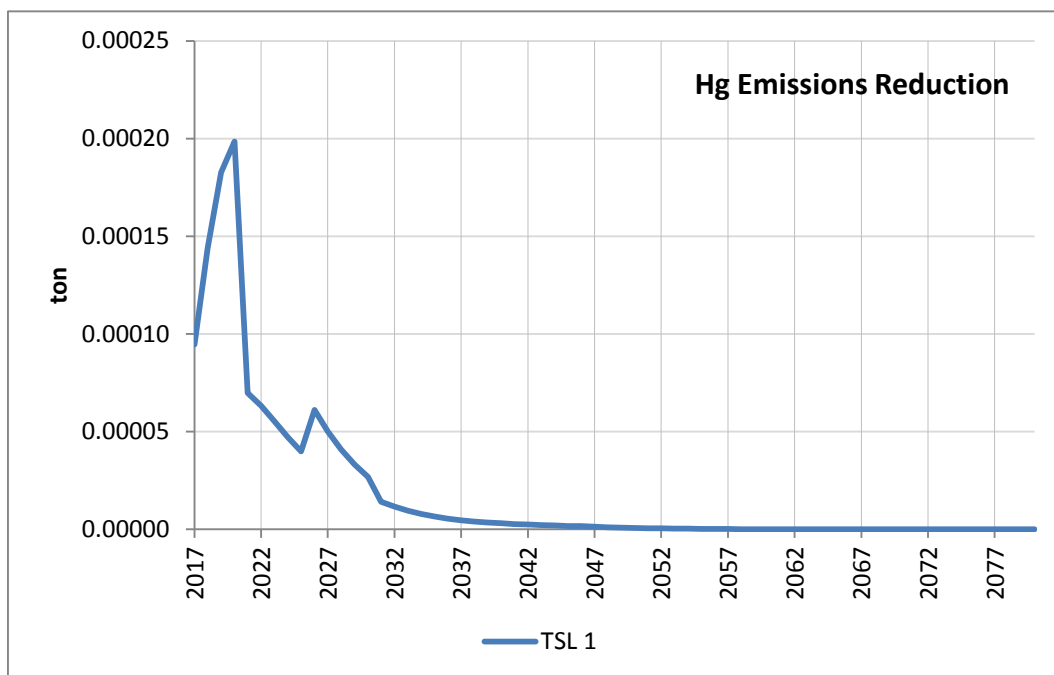


Figure 14.5.10 Hg Total Emissions Reduction for IRLs

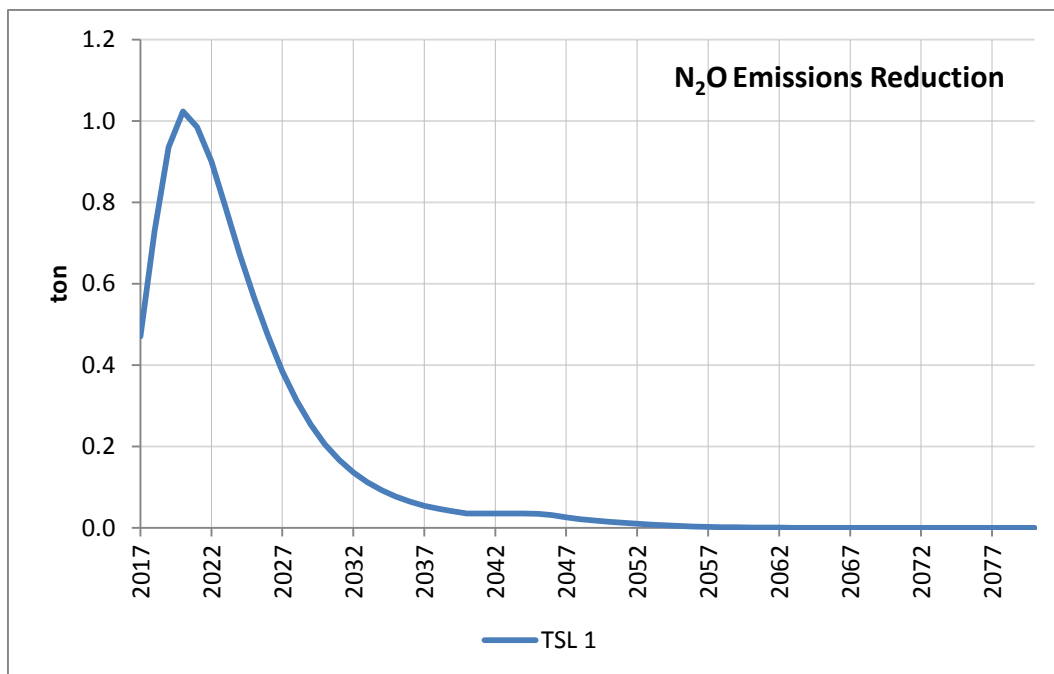


Figure 14.5.11 N₂O Total Emissions Reduction for IRLs

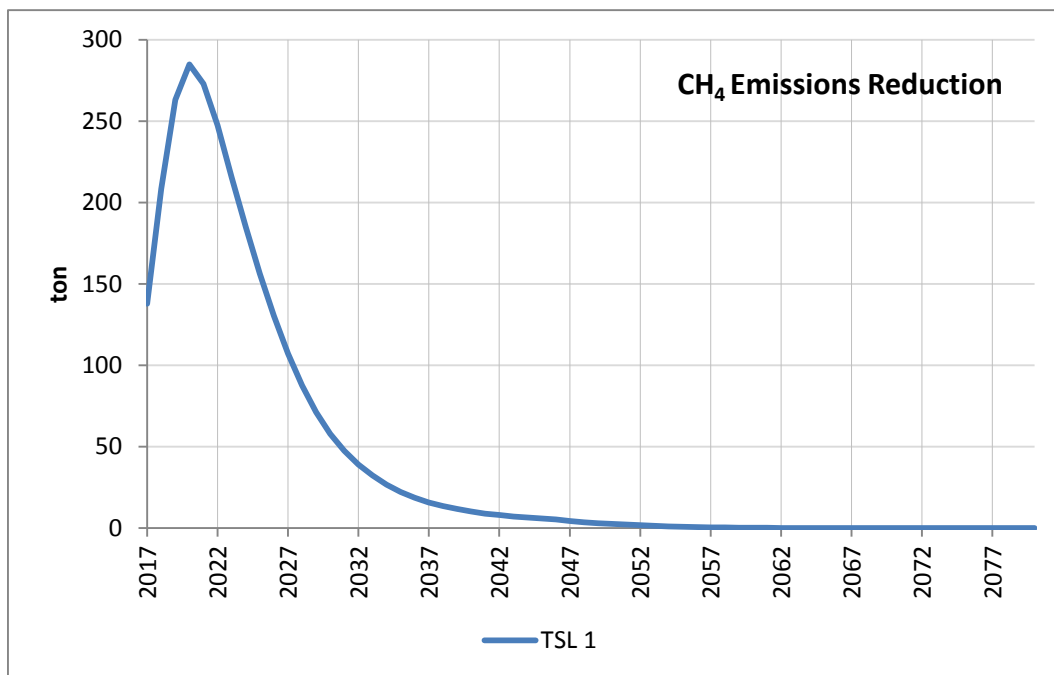


Figure 14.5.12 CH₄ Total Emissions Reduction for IRLs

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CHAPTER 15. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

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CHAPTER 15. MONETIZATION OF EMISSION REDUCTIONS BENEFITS

15.1 INTRODUCTION

As part of its assessment of energy conservation standards, DOE estimated the monetary benefits likely to result from the reduced emissions of carbon dioxide (CO₂) and nitrogen oxides (NO_x) that are expected to result from each of the TSLs considered. This chapter summarizes the basis for the monetary values used for each of these emissions and presents the benefits estimates considered.

15.2 MONETIZING CARBON DIOXIDE EMISSIONS

15.2.1 Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services. Estimates of the SCC are provided in dollars per metric ton of carbon dioxide. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

Under section 1(b)(6) of Executive Order 12866, "Regulatory Planning and Review," 58 FR 51735 (Oct. 4, 1993), agencies must, to the extent permitted by law, "assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." The purpose of the SCC estimates presented here is to allow agencies to incorporate the monetized social benefits of reducing CO₂ emissions into cost-benefit analyses of regulatory actions that have small, or "marginal," impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

As part of the interagency process that developed these SCC estimates, technical experts from numerous agencies met on a regular basis to explore the technical literature in relevant fields, discuss key model inputs and assumptions, and consider public comments. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

15.2.2 Monetizing Carbon Dioxide Emissions

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A report from the National Research Council¹ points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Most Federal regulatory actions can be expected to have marginal impacts on global emissions. For such policies, the agency can estimate the benefits from reduced (or costs from increased) emissions in any future year by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions.

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO₂ emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted. The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO₂.² These interim values represented the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules.

15.2.3 Current Approach and Key Assumptions

After the release of the interim values, the interagency group reconvened on a regular basis to generate improved SCC estimates, which were considered for this proposed rule. Specifically, the group considered public comments and further explored the technical literature in relevant fields. The interagency group relied on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.^a These models are

^a The models are described in appendix 14-A of the TSD.

frequently cited in the peer-reviewed literature and were used in the last assessment of the Intergovernmental Panel on Climate Change. Each model was given equal weight in the SCC values that were developed.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: (1) climate sensitivity; (2) socio-economic and emissions trajectories; and (3) discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socio-economic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. The values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although preference is given to consideration of the global benefits of reducing CO₂ emissions. Table 15.2.1 presents the values in the 2010 interagency group report,^b which is reproduced in appendix 14-A of the TSD.

The SCC values used for this analysis were generated using the most recent versions of the three integrated assessment models that have been published in the peer-reviewed literature, as described in the 2013 update³ from the interagency working group (revised November 2013).^c Table 15.2.2 shows the updated sets of SCC estimates in five year increments from 2010 to 2050. The full set of annual SCC estimates between 2010 and 2050 is reported in appendix 14-B of the TSD. The central value that emerges is the average SCC across models at the 3 percent discount rate. However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance of including all four sets of SCC values. For the years after 2050, DOE applied the average annual growth rate of the SCC estimates in 2040–2050 associated with each of the four sets of values.

^b *Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.

<http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/Social-Cost-of-Carbon-for-RIA.pdf>.

^c *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. Interagency Working Group on Social Cost of Carbon, United States Government. May 2013; revised November 2013. <http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf>.

Table 15.2.1 Annual SCC Values from 2010 Interagency Report, 2010–2050 (in 2007 dollars per metric ton of CO₂)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95 th Percentile
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Table 15.2.2 Annual SCC Values from 2013 Interagency Update, 2010–2050 (in 2007 dollars per metric ton of CO₂)

Year	Discount Rate %			
	5	3	2.5	3
	Average	Average	Average	95 th Percentile
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Research Council report mentioned above points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. There are a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC. The interagency group intends to periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling.

In summary, in considering the potential global benefits resulting from reduced CO₂ emissions, DOE used the values from the 2013 interagency report, escalated to 2012\$ using the GDP price deflator. For each of the four cases specified, the values used for emissions in 2015 are \$11.8, \$39.7, \$61.2, and \$117 per metric ton avoided.

DOE multiplied the CO₂ emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, the interagency report notes that damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency. Thus, DOE discounted the values in each of the four cases using the specific discount rate that had been used to obtain the SCC values in each case.

15.3 VALUATION OF OTHER EMISSIONS REDUCTIONS

DOE considered the potential monetary benefit of reduced NO_x emissions from the TSLs it considered. As noted in chapter 14, new or amended energy conservation standards would reduce NO_x emissions in those States that are not affected by caps. DOE estimated the monetized value of NO_x emissions reductions resulting from each of the TSLs considered based on environmental damage estimates found in the relevant scientific literature. Estimates of monetary value for reducing NO_x from stationary sources range from \$468 to \$4,809 per ton in 2012\$.⁴ DOE calculated monetary benefits using a medium value for NO_x emissions of \$2,639 per short ton (in 2012\$), and real discount rates of 3 percent and 7 percent.

DOE is still evaluating appropriate values to use to monetize avoided SO₂ and Hg emissions. It did not monetize these emissions for this analysis.

15.4 RESULTS

Table 15.4.1 and Table 15.4.2 present the global values of CO₂ emissions reductions for each considered TSL. DOE calculated domestic values as a range from 7 percent to 23 percent of the global values, and these results are presented in Table 15.4.3 and Table 15.4.4.

Table 15.4.5 and Table 15.4.6 present the present value of cumulative NO_x emissions reductions for each TSL, calculated using the average dollar-per-ton values and seven-percent and three-percent discount rates.

**Table 15.4.1 Estimates of Global Present Value of CO₂ Emissions Reduction for GSFL
Trial Standard Levels**

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95 th percentile*
	<u>Million 2012\$</u>			
Power Sector Energy Emissions				
1	77.2	333	522	1,018
2	76.4	328	515	1,004
3	325	1,405	2,208	4,302
4	1,072	4,669	7,349	14,315
5	1,231	5,349	8,415	16,396
Upstream Emissions				
1	4.03	17.5	27.5	53.5
2	3.97	17.2	27.0	52.6
3	17.0	74.0	117	227
4	56.7	249	392	764
5	65.0	284	448	873
Total Emissions				
1	81.3	350	550	1,072
2	80.4	345	542	1,057
3	342	1,479	2,325	4,529
4	1,129	4,918	7,741	15,079
5	1,296	5,633	8,863	17,270

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is \$11.8, \$39.7, \$61.2, and \$117 per metric ton (2012\$).

**Table 15.4.2 Estimates of Global Present Value of CO₂ Emissions Reduction for IRL
Trial Standard Levels**

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95 th percentile*
	<u>Million 2012\$</u>			
Power Sector Energy Emissions				
1	5.83	23.8	37.0	71.9
Upstream Emissions				
1	0.282	1.15	1.80	3.49
Total Emissions				
1	6.12	24.9	38.8	75.4

* For each of the four cases, the corresponding global SCC value for emissions in 2015 is \$11.8, \$39.7, \$61.2, and \$117 per metric ton (2012\$).

Table 15.4.3 Estimates of Domestic Present Value of CO₂ Emissions Reduction for GSFL Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95 th percentile*
	<u>Million 2012\$</u>			
Power Sector Energy Emissions				
1	5.4 to 17.8	23.3 to 76.5	36.6 to 120.2	71.3 to 234.2
2	5.3 to 17.6	23.0 to 75.5	36.1 to 118.5	70.3 to 230.9
3	22.8 to 74.8	98.4 to 323.2	154.6 to 507.9	301.2 to 989.5
4	75.1 to 246.7	326.8 to 1073.9	514.4 to 1690.2	1002.0 to 3292.4
5	86.1 to 283.1	374.4 to 1230.3	589.1 to 1935.5	1147.7 to 3771.2
Upstream Emissions				
1	0.3 to 0.9	1.2 to 4.0	1.9 to 6.3	3.7 to 12.3
2	0.3 to 0.9	1.2 to 3.9	1.9 to 6.2	3.7 to 12.1
3	1.2 to 3.9	5.2 to 17.0	8.2 to 26.8	15.9 to 52.2
4	4.0 to 13.0	17.4 to 57.2	27.5 to 90.2	53.5 to 175.8
5	4.5 to 14.9	19.9 to 65.4	31.4 to 103.1	61.1 to 200.9
Total Emissions				
1	5.7 to 18.7	24.5 to 80.5	38.5 to 126.5	75.0 to 246.5
2	5.6 to 18.5	24.2 to 79.4	37.9 to 124.7	74.0 to 243.0
3	24.0 to 78.8	103.5 to 340.2	162.7 to 534.7	317.0 to 1041.7
4	79.0 to 259.7	344.3 to 1131.1	541.9 to 1780.4	1055.5 to 3468.2
5	90.7 to 298.0	394.3 to 1295.7	620.4 to 2038.6	1208.9 to 3972.0

* For each of the four cases, the corresponding SCC value for emissions in 2015 is \$11.8, \$39.7, \$61.2, and \$117 per metric ton (2012\$).

Table 15.4.4 Estimates of Domestic Present Value of CO₂ Emissions Reduction for IRL Trial Standard Levels

TSL	SCC Case*			
	5% discount rate, average*	3% discount rate, average*	2.5% discount rate, average*	3% discount rate, 95 th percentile*
	<u>Million 2012\$</u>			
Power Sector Energy Emissions				
1	0.4 to 1.3	1.7 to 5.5	2.6 to 8.5	5.0 to 16.5
Upstream Emissions				
1	0.0 to 0.1	0.1 to 0.3	0.1 to 0.4	0.2 to 0.8
Total Emissions				
1	0.4 to 1.4	1.7 to 5.7	2.7 to 8.9	5.3 to 17.3

* For each of the four cases, the corresponding SCC value for emissions in 2015 is \$11.8, \$39.7, \$61.2, and \$117 per metric ton (2012\$).

Table 15.4.5 Estimates of Present Value of NO_x Emissions Reduction for GSFL Trial Standard Levels

TSL	3% discount rate	7% discount rate
	<u>Million 2012\$</u>	
Power Sector Emissions		
1	9.55	5.83
2	9.50	5.84
3	40.0	24.3
4	129	76.9
5	149	88.6
Upstream Emissions		
1	11.8	6.88
2	11.7	6.85
3	49.9	28.8
4	165	92.8
5	189	107
Total Emissions		
1	21.4	12.7
2	21.2	12.7
3	89.9	53.1
4	295	170
5	338	195

Table 15.4.6 Estimates of Present Value of NO_x Emissions Reduction for IRL Trial Standard Levels

Standard Levels		
TSL	3% discount rate	7% discount rate
	<u>Million 2012\$</u>	
Power Sector Emissions		
1	0.708	0.517
Upstream Emissions		
1	0.867	0.605
Total Emissions		
1	1.58	1.12

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CHAPTER 16. UTILITY IMPACT ANALYSIS

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CHAPTER 16. UTILITY IMPACT ANALYSIS

16.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL).

The utility impact analysis uses a variant of the DOE Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).^a NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). DOE uses a variant of this model, referred to as NEMS-BT,^b to account for selected utility impacts from energy conservation standards. DOE's analysis consists of a comparison between model results for the most recent AEO Reference Case and for cases in which energy use is decremented to reflect the impacts of standards. For the analysis of standards for GSFLs and IRLs DOE used the version of NEMS based on *AEO 2013*.¹

NEMS-BT has a number of advantages that have led to its use in the analysis of energy conservation standards:

- NEMS-BT uses a set of assumptions that are well known and fairly transparent, due to the exposure and scrutiny each *AEO* receives.
- NEMS-BT is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS-BT permits the modeling of interactions among the various energy supply and demand sectors.

16.2 METHODOLOGY

DOE uses NEMS-BT to estimate the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards. In practice, the numerical differences between

^a For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is National Energy Modeling System: An Overview 2003, DOE/EIA-0581(2003) (March, 2003).

^b DOE/EIA approves use of the name NEMS to describe only an official version of the model without any modification to code or data. Because this analysis entails some minor code modifications and the model is run under various policy scenarios that are variations on DOE/EIA assumptions, DOE refers to it by the name NEMS-BT (BT is DOE's Building Technologies Program, under whose aegis this work has been performed).

marginal and average values may turn out to be smaller than the intrinsic uncertainties in the AEO.

NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation (terawatt hours, TWh) from the stock of electric generating capacity changes, the total generation capacity itself (gigawatts, GW) may change, and the mix of capacity by fuel type may change. Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use.

To model the impact of a standard, DOE inputs a reduction to annual energy demand for the corresponding end use in the appropriate start year. The NEMS-BT model is run with the decremented energy demand to determine the modified build-out of capacity and total generation. Regional effects of a standard can be accounted for by defining the energy demand decrement as a function of census division.

The output of the NEMS-BT analysis includes the effective marginal heat rate (ratio of the change in energy consumption in quads to the change in generation in TWh), and the capacity reduction by plant type for a given reduction in total generation. DOE uses the site energy savings multiplied by a transmission-and-distribution (T&D) loss factor to estimate the reduction in generation for each TSL. The relationship between a reduction^c in electricity generation (TWh) and the reduction in capacity (GW) is estimated based on the output of NEMS-BT model runs using the end-use specific energy demand decrement. Details on the approach used may be found in Coughlin (2013).²

NEMS-BT provides output for the following capacity types: coal, nuclear, combined cycle (natural gas), renewable sources, oil and natural gas steam, combustion turbine/diesel, pumped storage, fuel cells, and distributed generation (natural gas). DOE grouped oil and natural gas steam and combustion turbine/diesel into a “peaking” category, and grouped pumped storage, fuel cells, and distributed generation (natural gas) into an “other” category.

In general, energy conservation standards impact primarily fossil combustion (coal, natural gas and diesel) and renewables. Pumped storage and nuclear power are very insensitive to small changes in demand, while fuel cells and distributed generation make up a very small fraction (less than 1 percent) of the generation capacity base.

For the analysis of GSFLs and IRLs, DOE derived factors based on the plant types used to supply electricity for residential and commercial lighting.

^c These reductions are defined relative to the AEO Reference case.

16.3 UTILITY IMPACT RESULTS

This section presents results of the analysis for all of the capacity types except “Other”, for which the impacts are very small.

16.3.1 Installed Capacity

The figures in this section show the changes in U.S. electricity installed capacity that result for each TSL by major plant type for selected years. The changes have been calculated based on factors (megawatts (MW) of capacity reduction per gigawatt hours (GWh) of generation reduction) estimated from NEMS-BT model runs that simulated decrements in energy demand to either residential lighting or commercial lighting. Note that a positive change means a reduction in capacity under a TSL.

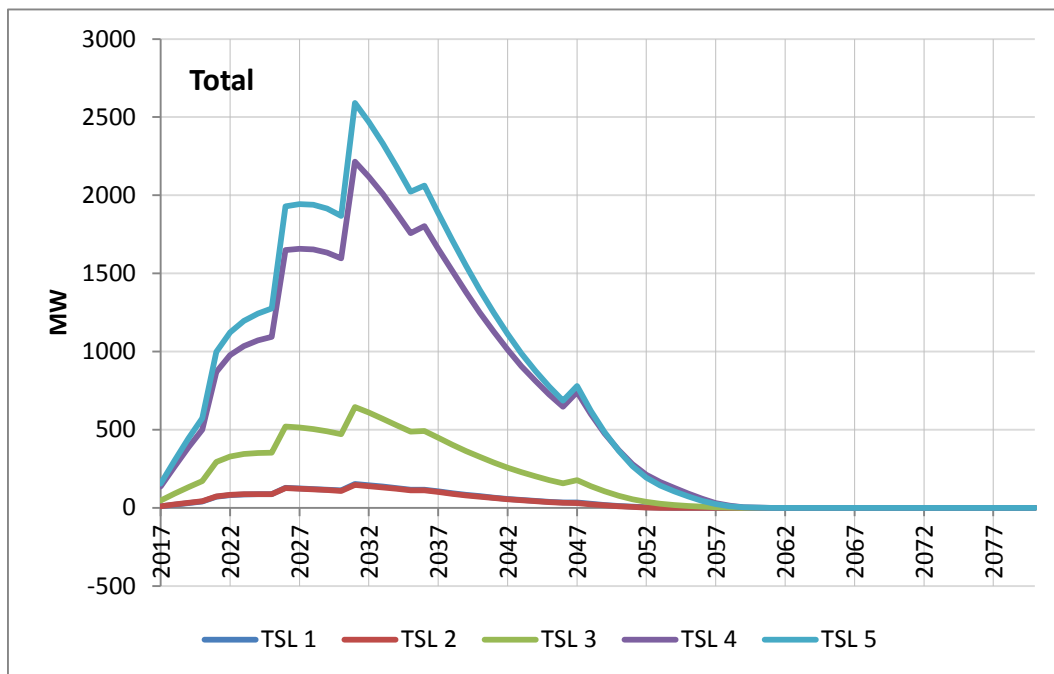


Figure 16.3.1 GSFL Total Electric Capacity Reduction

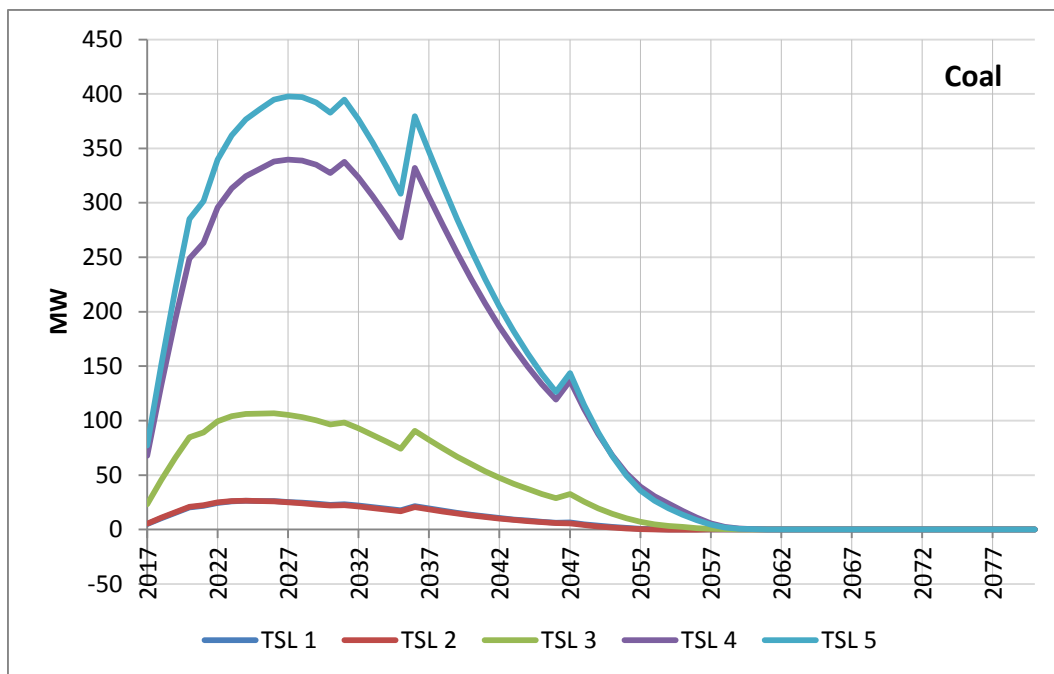


Figure 16.3.2 GSFL Coal Capacity Reduction

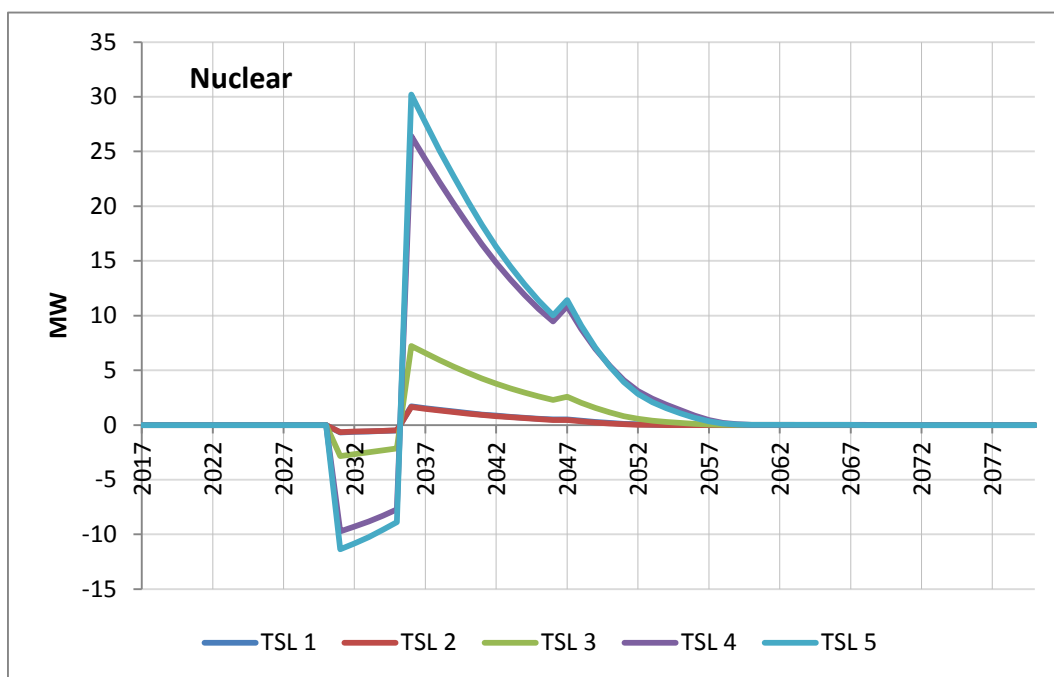


Figure 16.3.3 GSFL Nuclear Capacity Reduction

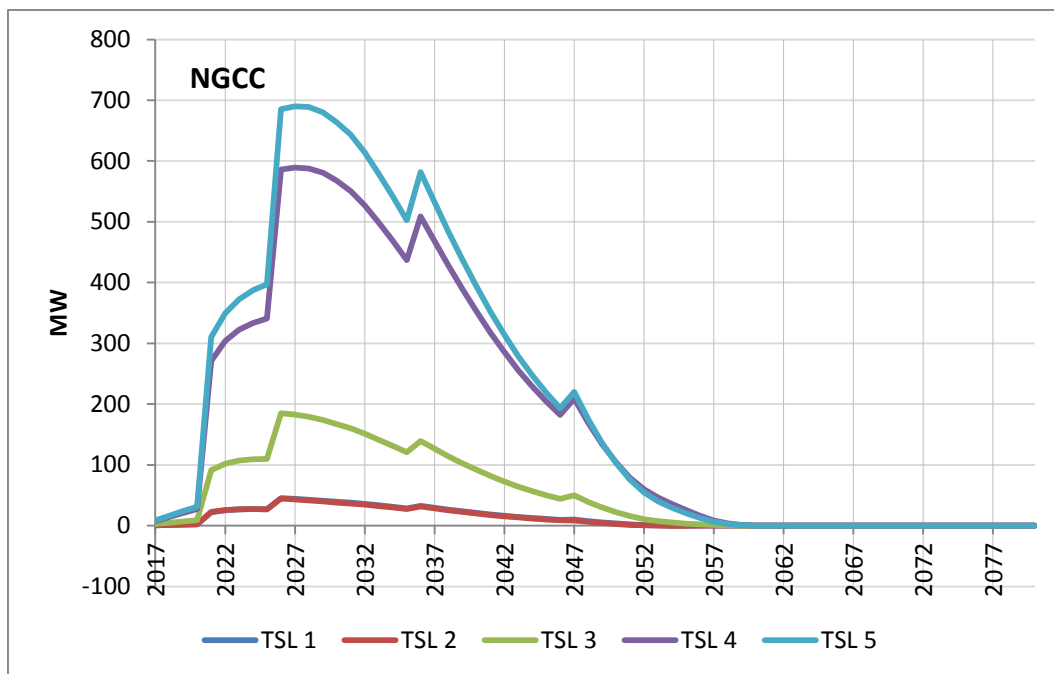


Figure 16.3.4 GSFL Gas Combined Cycle Capacity Reduction

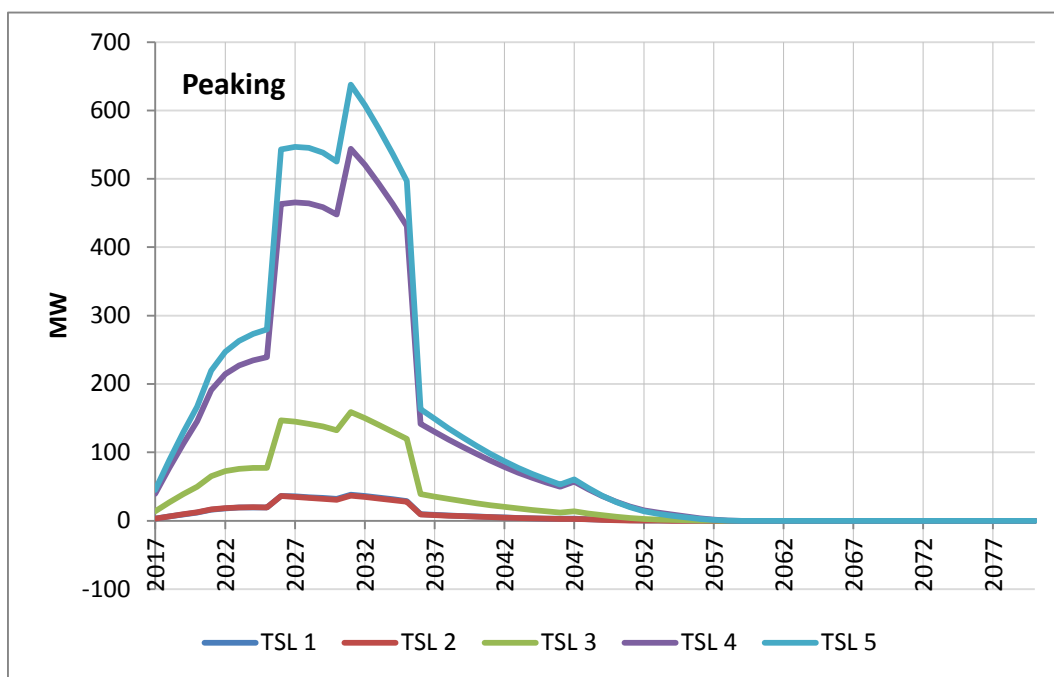


Figure 16.3.5 GSFL Peaking Capacity Reduction

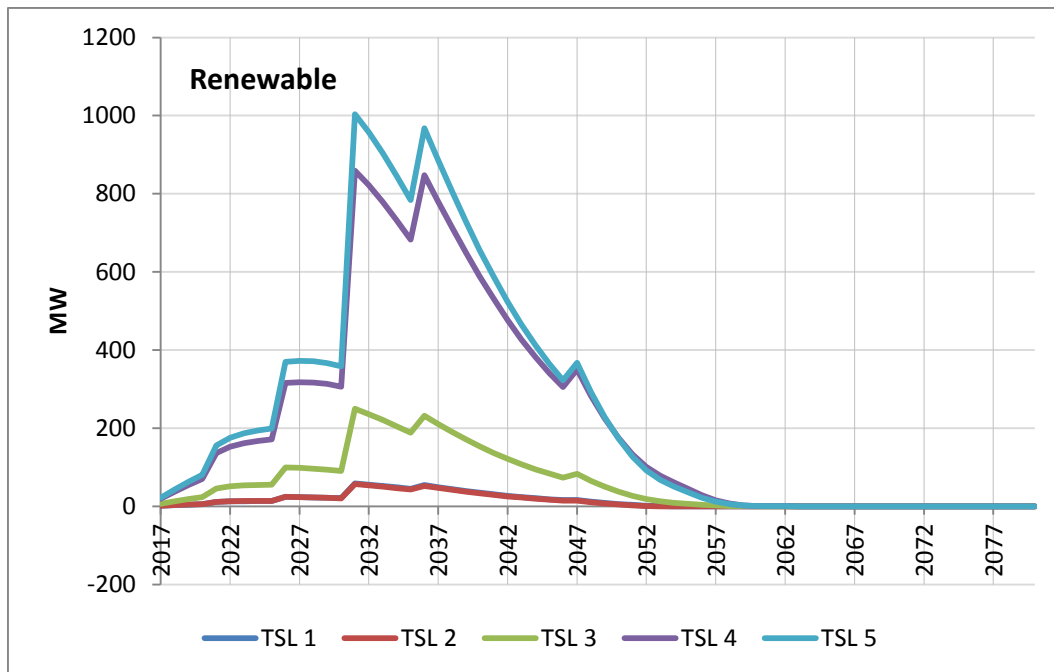


Figure 16.3.6 GSFL Renewables Capacity Reduction

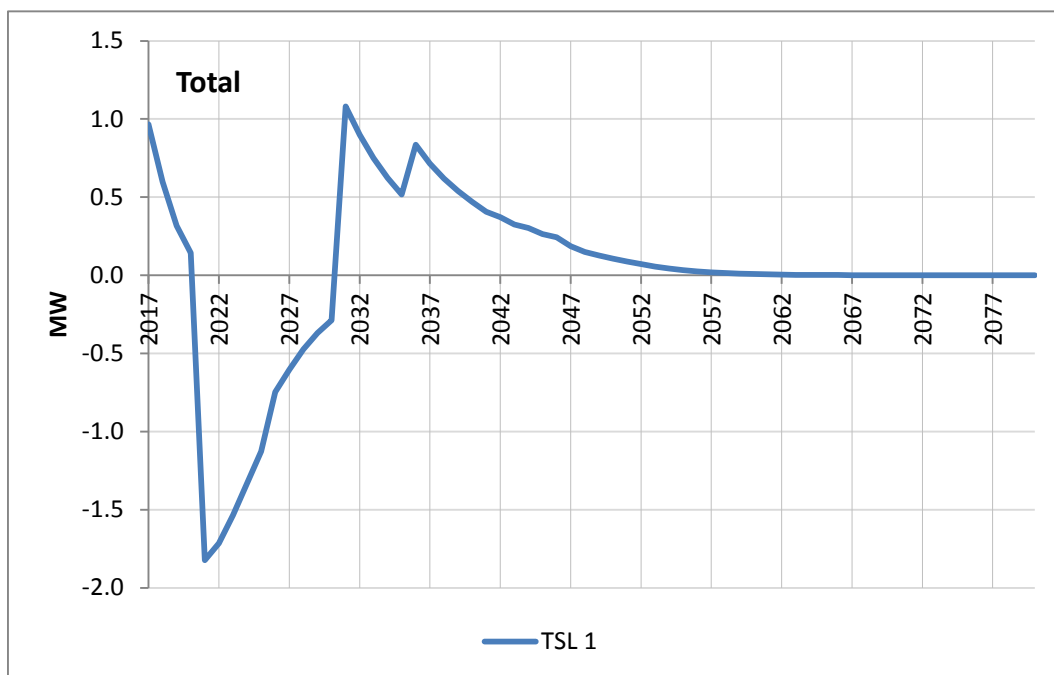


Figure 16.3.7 IRL Total Electric Capacity Reduction

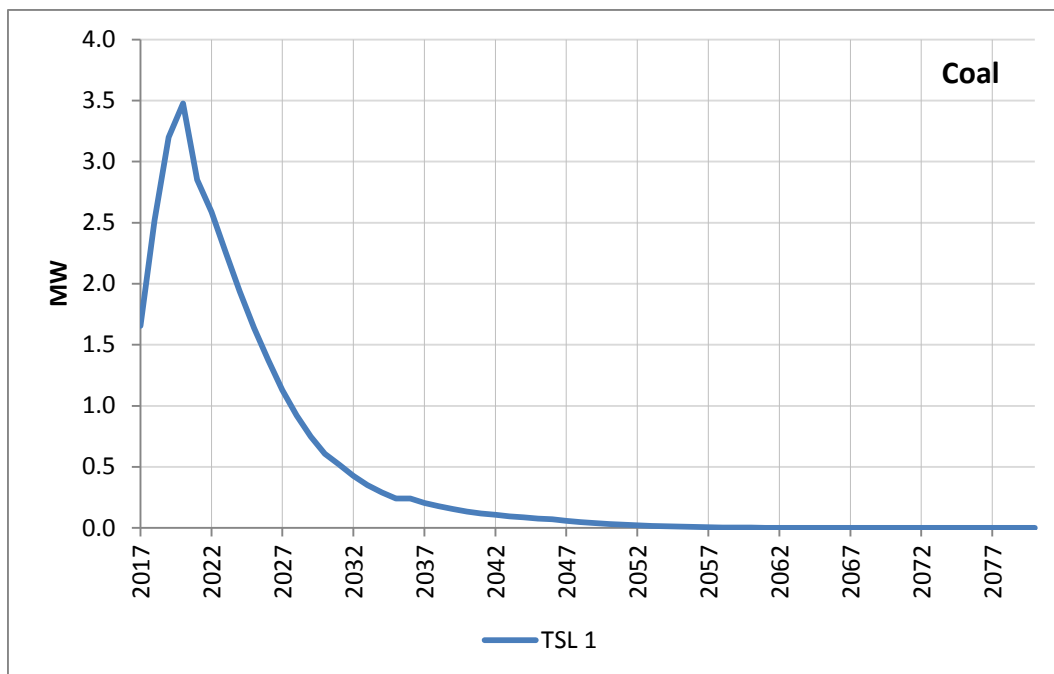


Figure 16.3.8 IRL Coal Capacity Reduction

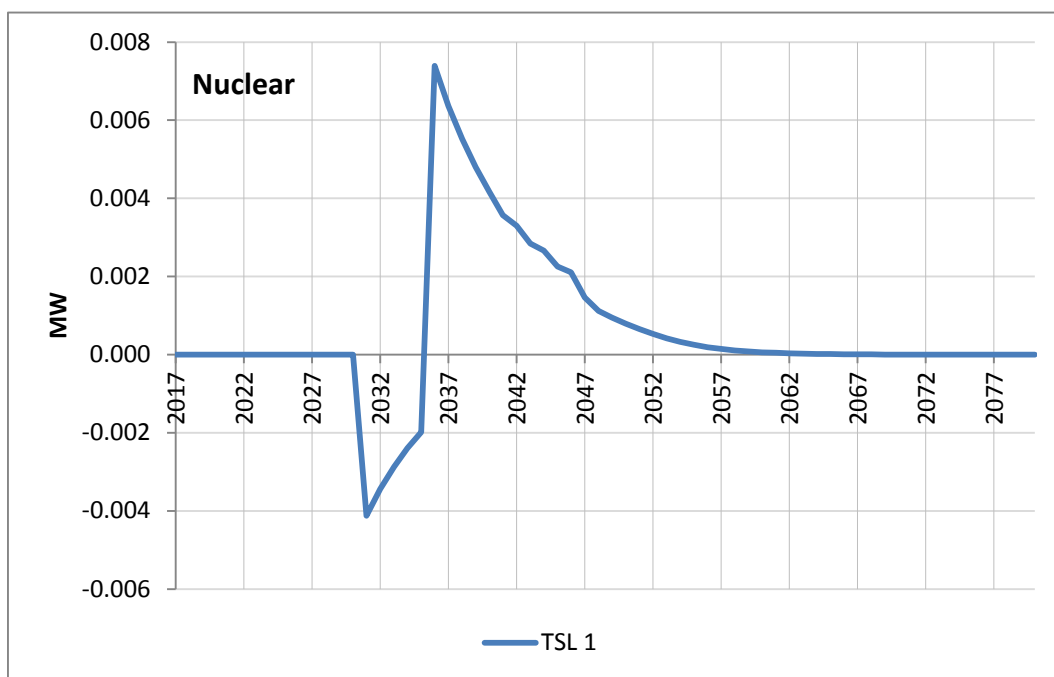


Figure 16.3.9 IRL Nuclear Capacity Reduction

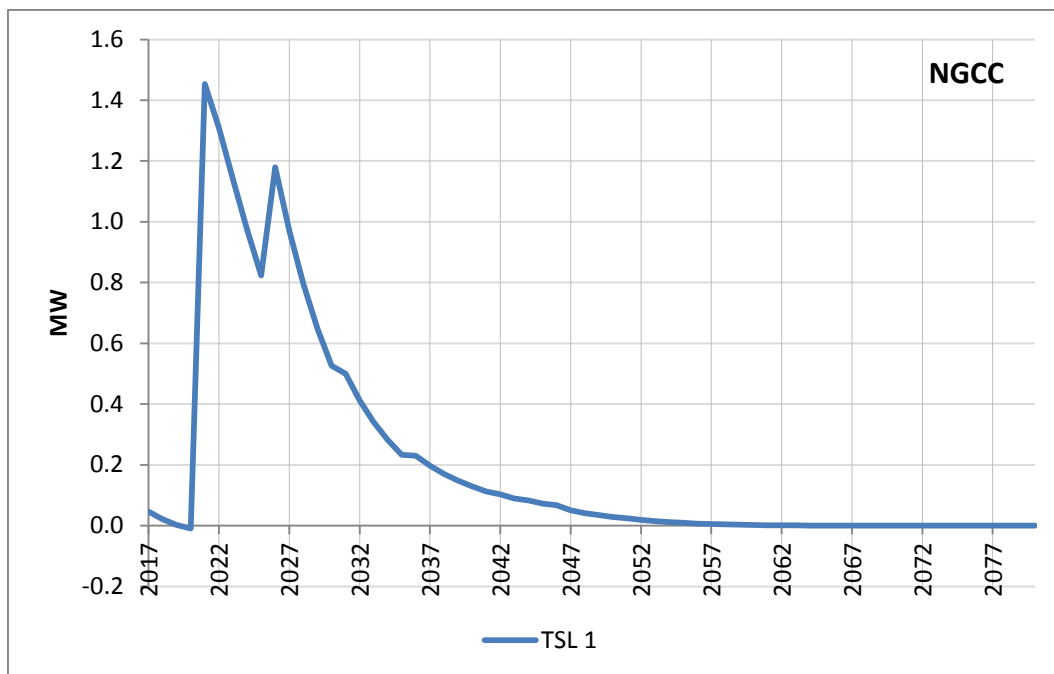


Figure 16.3.10 IRL Gas Combined Cycle Capacity Reduction

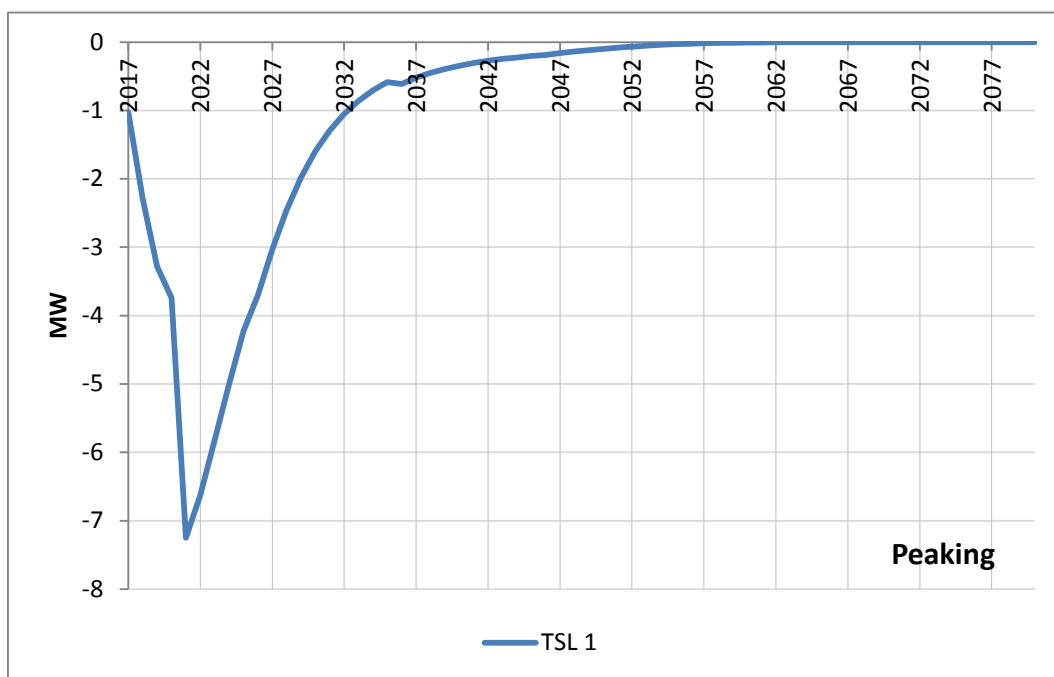


Figure 16.3.11 IRL Peaking Capacity Reduction

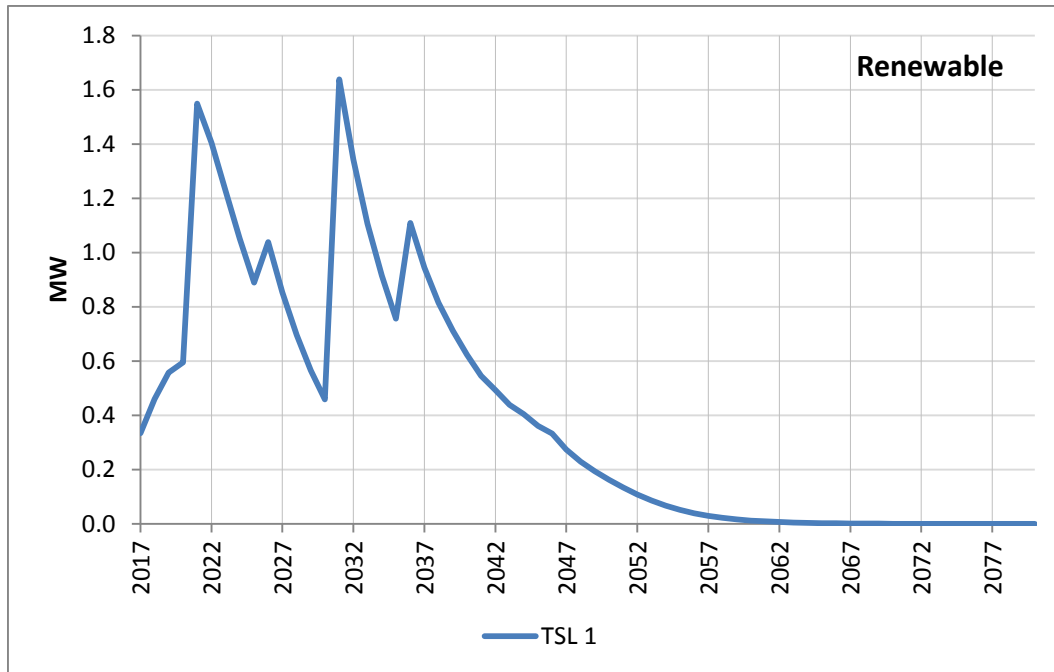


Figure 16.3.12 IRL Renewables Capacity Reduction

16.3.2 Electricity Generation

The figures in this section show the annual change in electricity generation that result for each TSL by plant type. The change by capacity type has been calculated based on shares (percentage of generation reduction for each capacity type over total generation reduction) estimated from NEMS-BT model runs which simulated decrements in energy demand to either residential lighting or commercial lighting. Note that a positive change means a reduction in generation under a TSL.

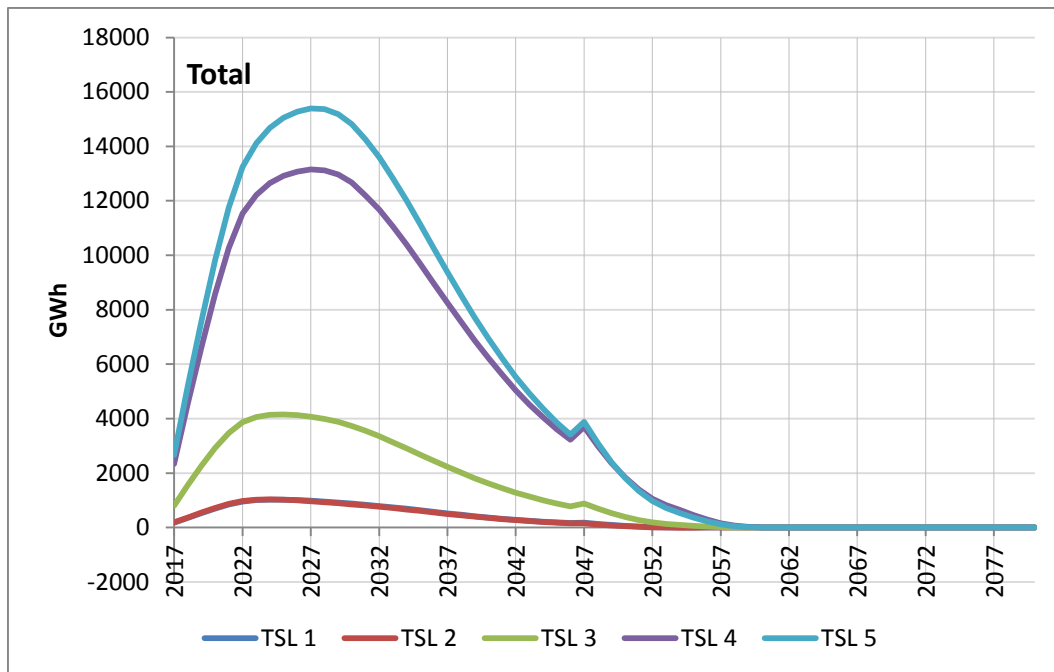


Figure 16.3.13 GSFL Total Generation Reduction

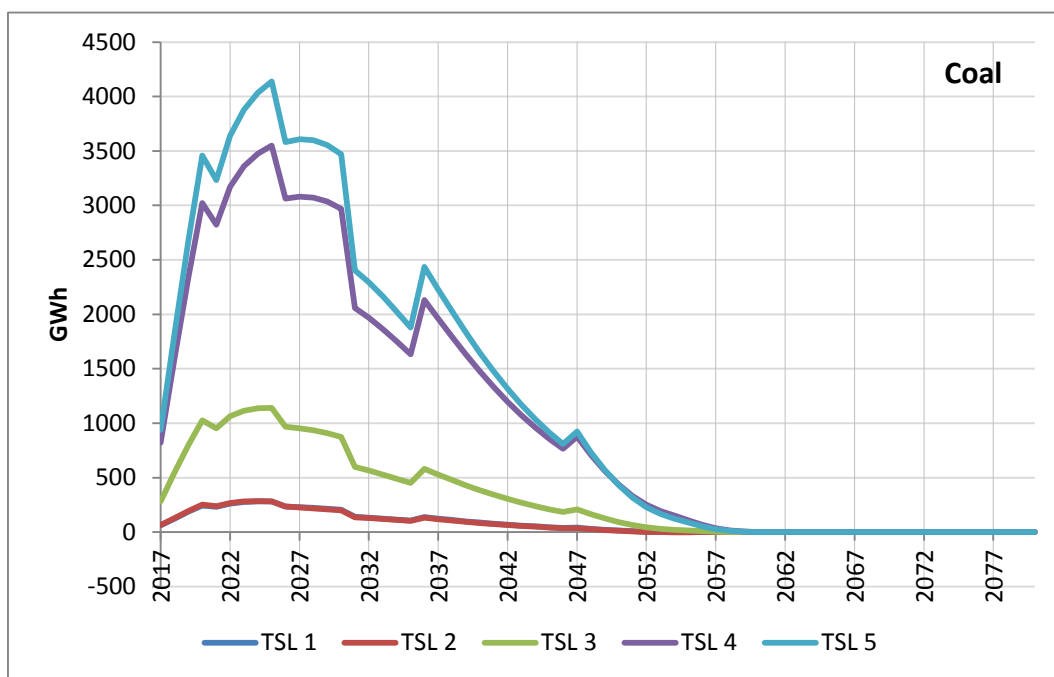


Figure 16.3.14 GSFL Coal Generation Reduction

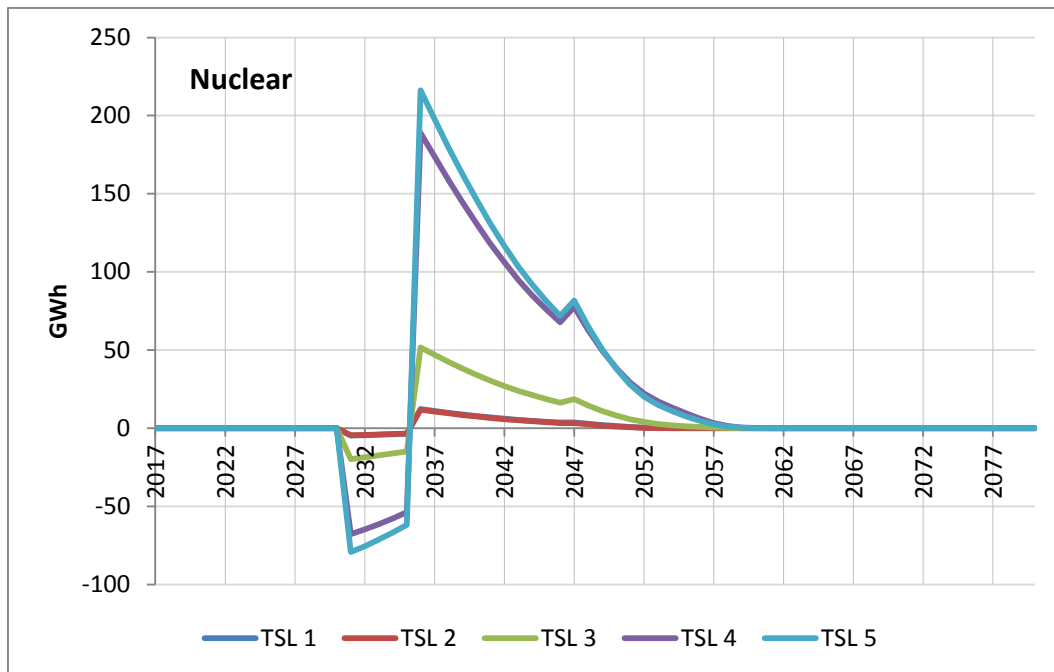


Figure 16.3.15 GSFL Nuclear Generation Reduction

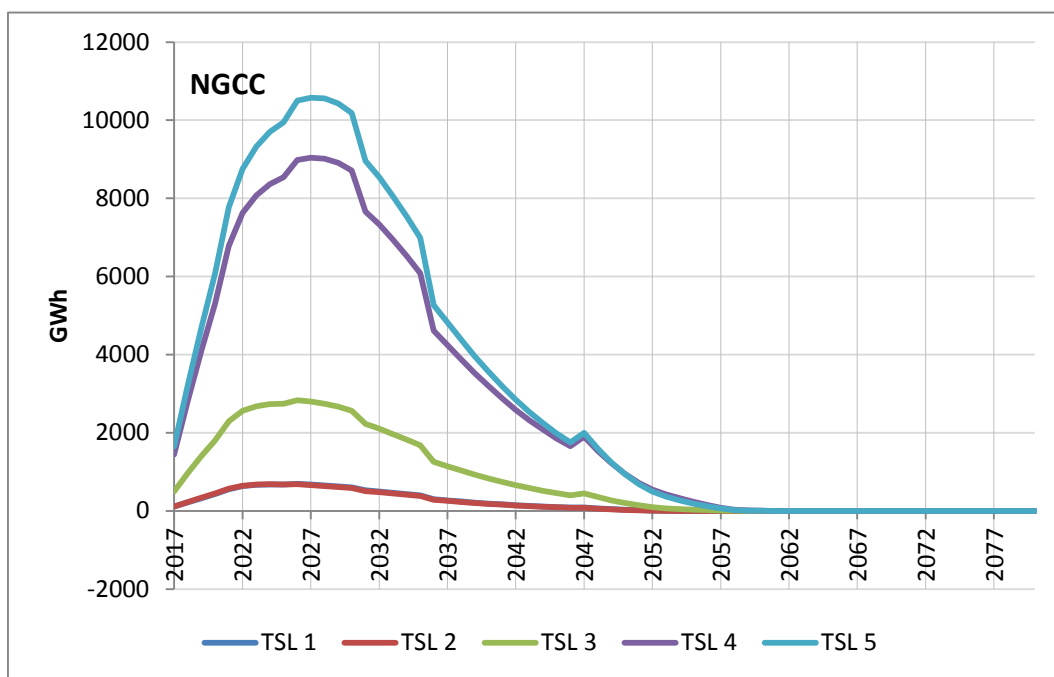


Figure 16.3.16 GSFL Gas Combined Cycle Generation Reduction

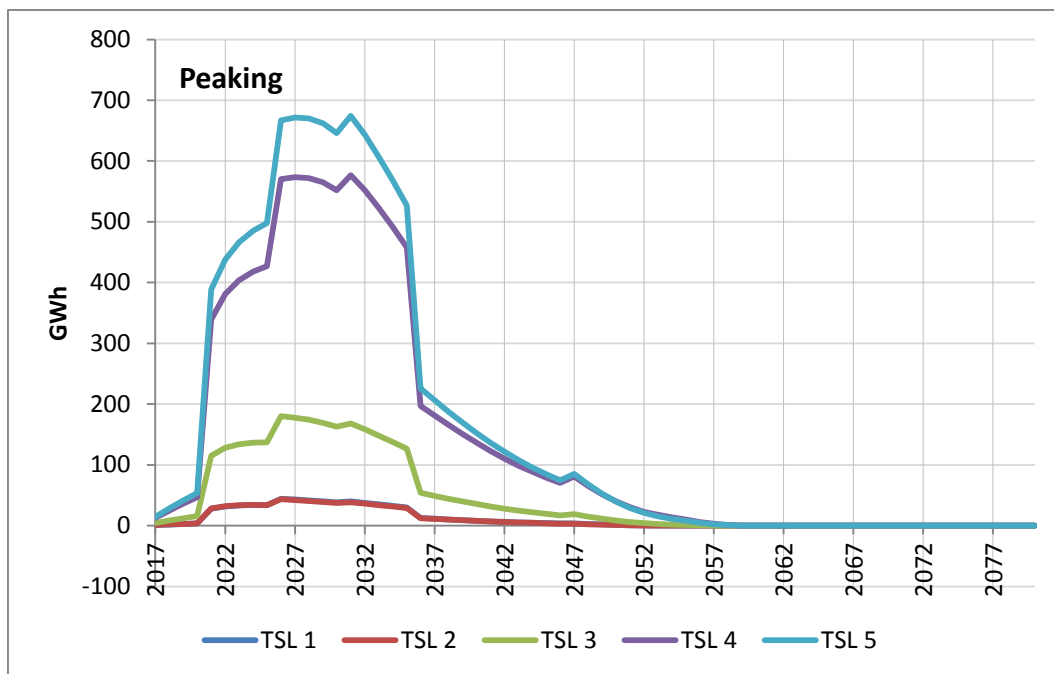


Figure 16.3.17 GSFL Peaking Generation Reduction

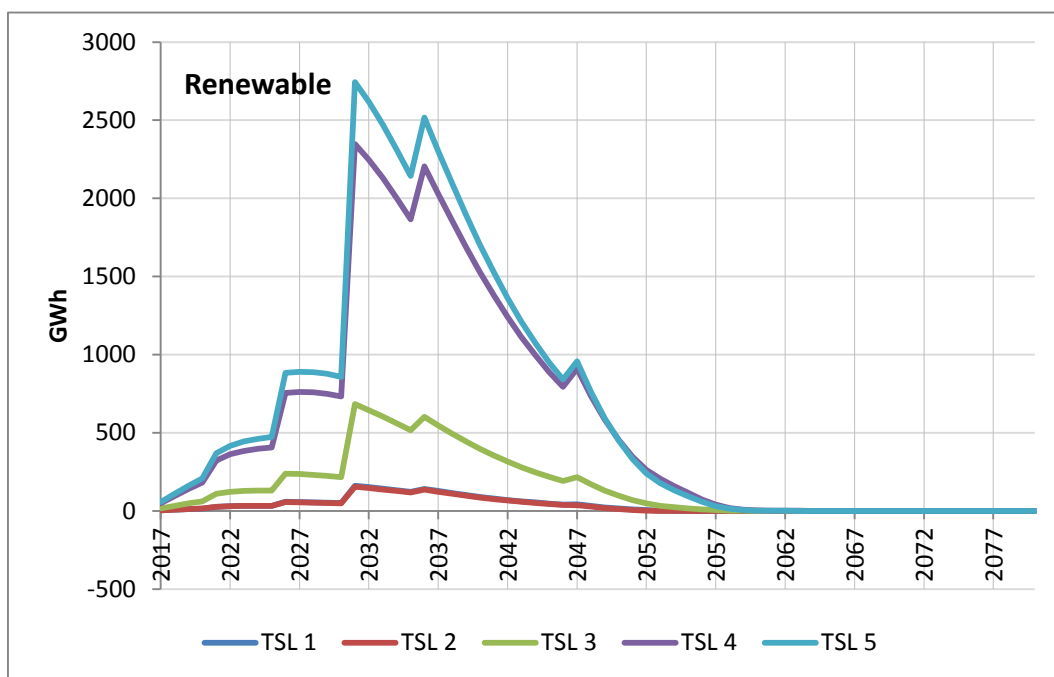


Figure 16.3.18 GSFL Renewables Generation Reduction

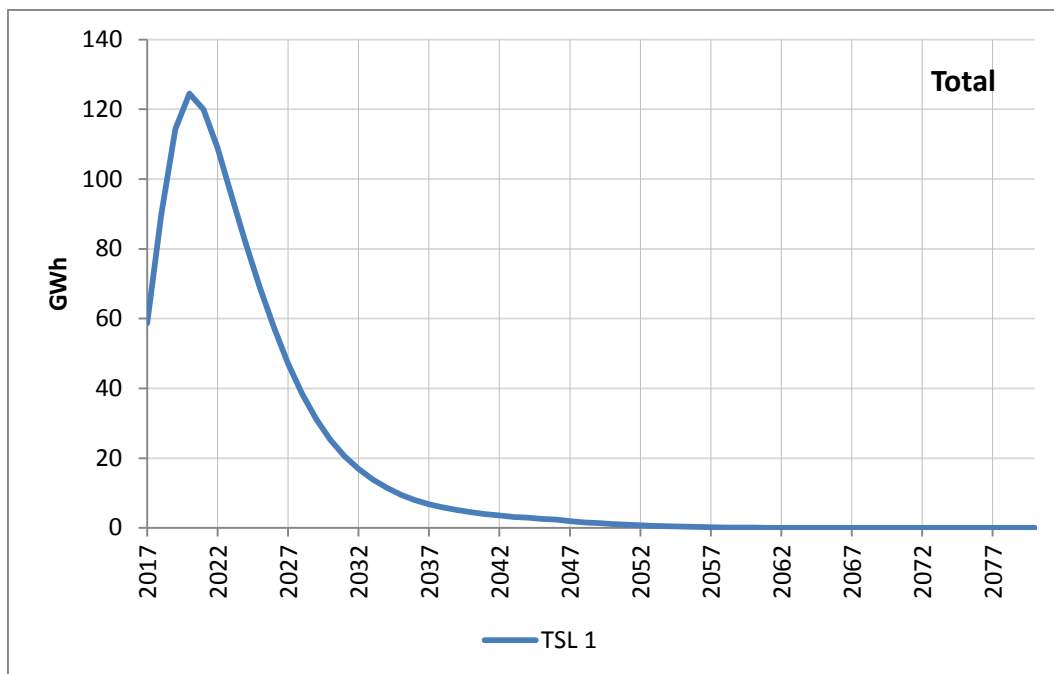


Figure 16.3.19 IRL Total Generation Reduction

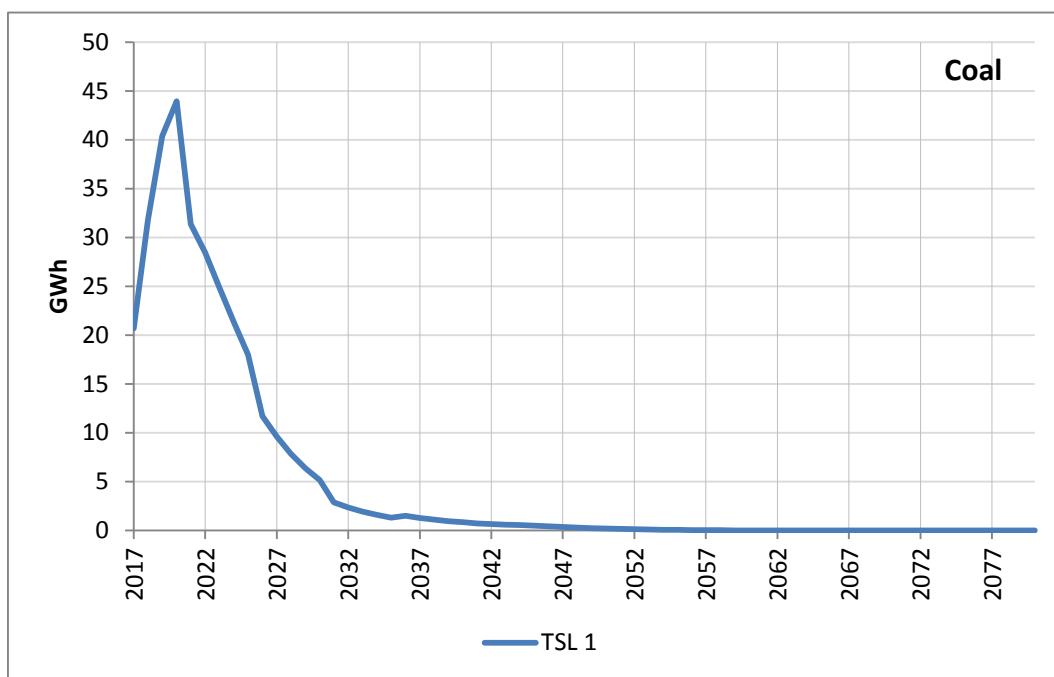


Figure 16.3.20 IRL Coal Generation Reduction

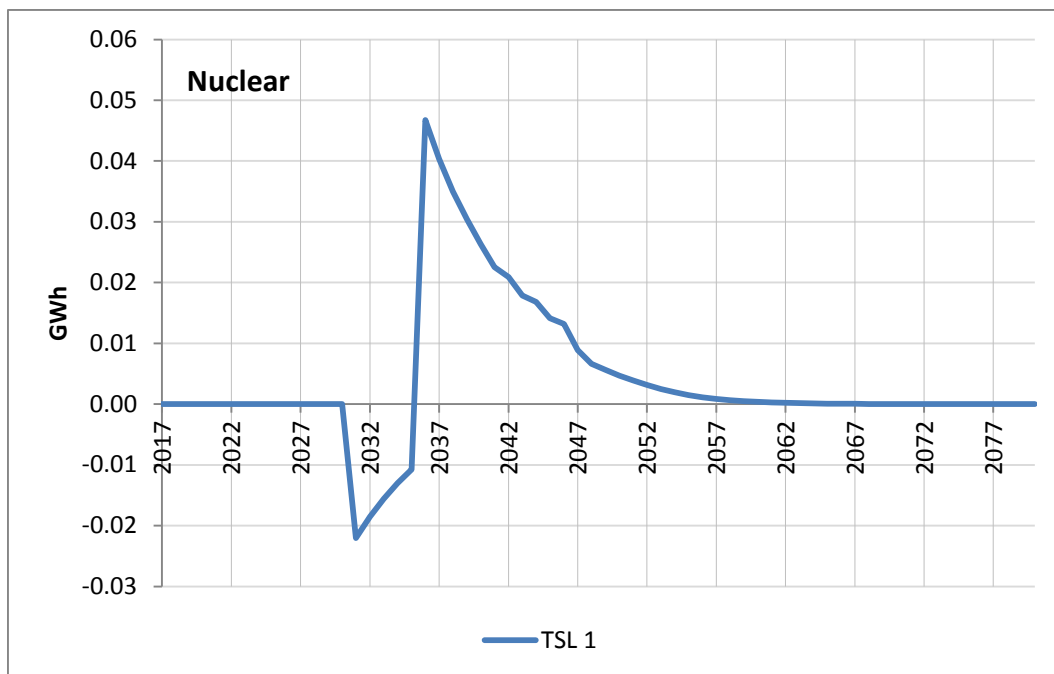


Figure 16.3.21 IRL Nuclear Generation Reduction

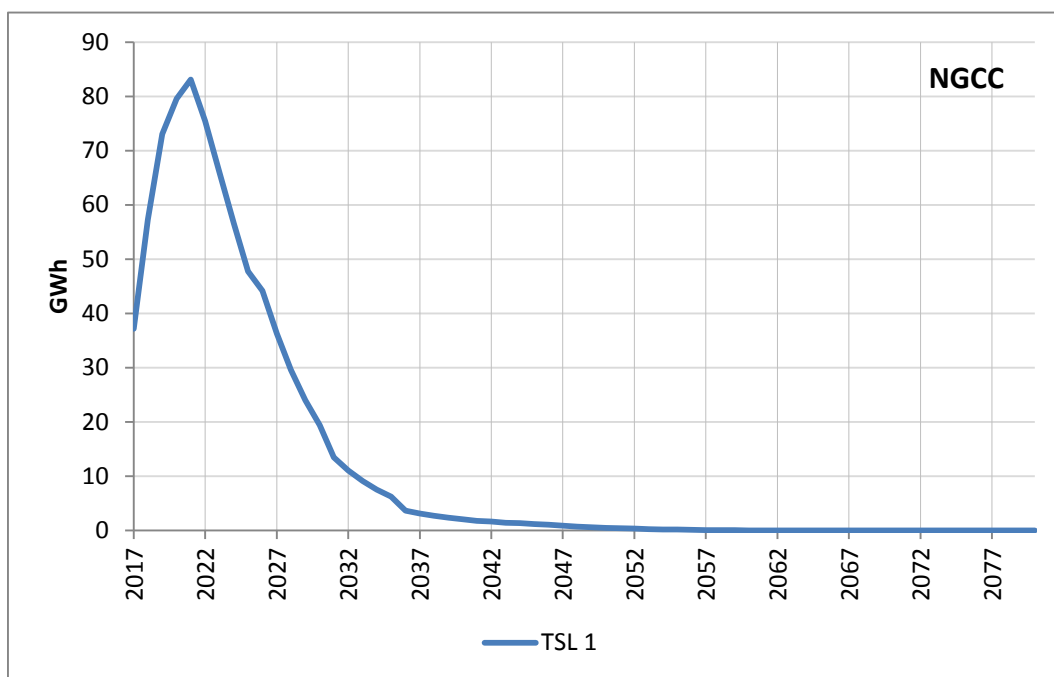


Figure 16.3.22 IRL Gas Combined Cycle Generation Reduction

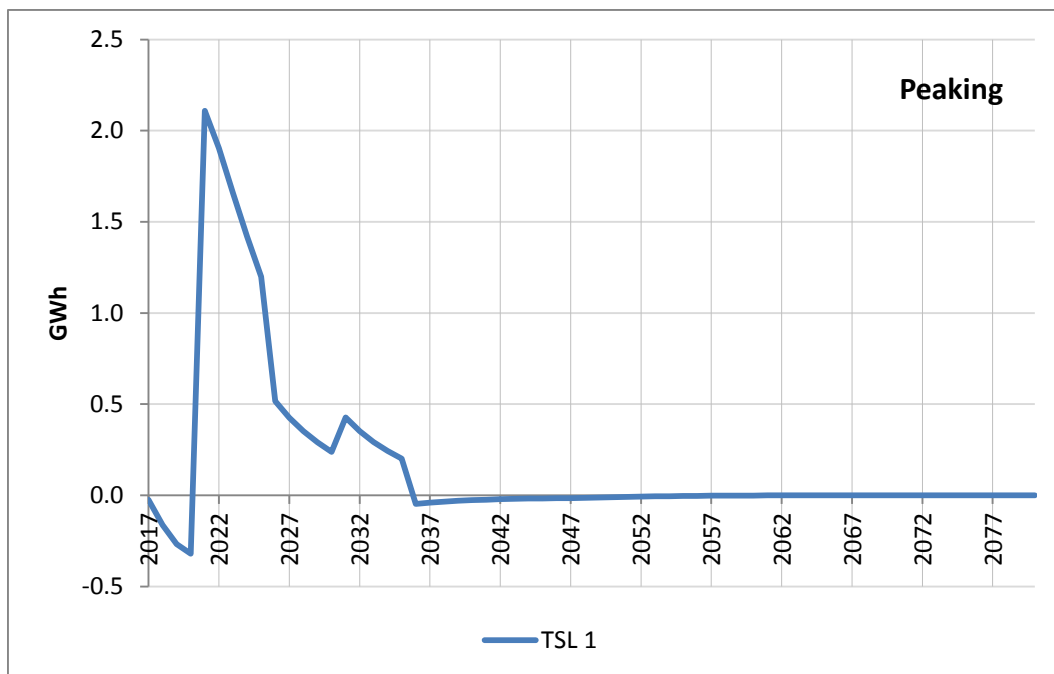


Figure 16.3.23 IRL Peaking Generation Reduction

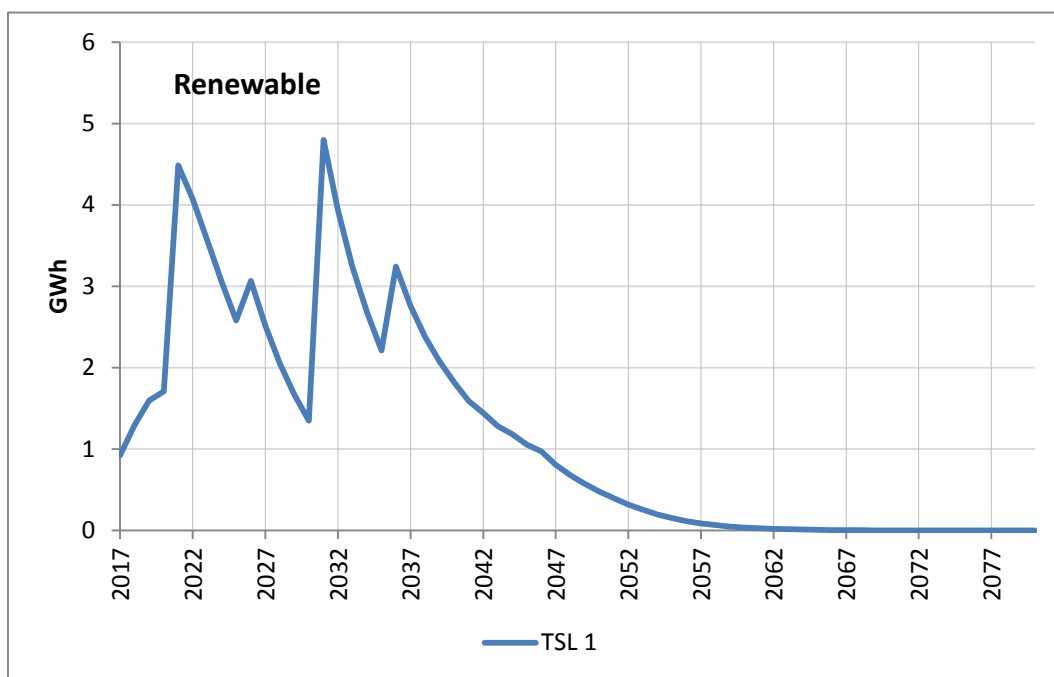


Figure 16.3.24 IRL Renewables Generation Reduction

16.3.3 Results Summary

Table 16.3.1 and Table 16.3.2 present a summary of the estimated utility impact results for GSFLs and IRLs.

Table 16.3.1 Summary of Utility Impact Results for GSFLs

	TSL				
	1	2	3	4	5
Installed Capacity Reduction (MW)					
2020	40.8	42.2	170	500	573
2025	87.4	87.3	352	1,093	1,275
2030	112	108	471	1,596	1,868
2035	116	112	487	1,758	2,022
2040	74.3	71.0	326	1,249	1,394
Electricity Generation Reduction (GWh)					
2020	696	719	2,917	8,572	9,814
2025	1,026	1,025	4,155	12,919	15,054
2030	881	850	3,734	12,670	14,813
2035	634	611	2,682	9,690	11,137
2040	368	352	1,622	6,224	6,938

Table 16.3.2 Summary of Utility Impact Results for IRLs

	TSL
	1
Installed Capacity Reduction (MW)	
2020	0.143
2025	-1.13
2030	-0.287
2035	0.516
2040	0.470
Electricity Generation Reduction (GWh)	
2020	124
2025	68.9
2030	25.3
2035	9.53
2040	4.51

16.4 AVOIDED CAPACITY VALUATION

Section 16.3.1 described the reduction in electricity generation capacity resulting from potential standards for GSFLs and IRLs. DOE used NEMS-BT to calculate a time series of capacity additions for only the GSFL standards cases as well as the base case to model avoided

capacity. Capacity additions refer to all power plants built; they may replace retired power plants or they may add new capacity to the power system. The cost of these annual capacity additions is determined by multiplying the capacity addition (in MW) by the cost of building new capacity. Table 16.4.1 shows the plant types and their associated plant costs as estimated by EIA, as well as how DOE matched the NEMS plant types to the EIA categories.

Table 16.4.1 Capital Costs for Electricity Generation Capacity

Plant Type	NEMS Capacity Type	Overnight Capital Cost* (2010 \$/kW)
Coal (Dual Unit Advanced PC)	Coal	\$2,844
Natural Gas (Conventional NGCC)	Combined Cycle	\$978
Natural Gas(Conventional CT)	Combustion Turbine/Diesel	\$974
Natural Gas (Advanced CT)	Distributed Generation (primarily peak-load capacity fueled by natural gas)	\$665
Average Renewables	Renewable Sources (includes conventional hydroelectric, geothermal, wood, wood waste, municipal waste, landfill gas, other biomass)	\$4,945

Source: Energy Information Administration, *Updated Capital Cost Estimates for Electricity Generation Plants*, November 2010. Washington, DC.

* EIA updates its cost assumptions for electric generating capacity annually as part of the development of the *Annual Energy Outlook* (AEO). The “overnight” capital cost for a power plant is an estimate of the cost of building an entire power plant from planning through completion assuming that it is accomplished in a single day. This serves as a starting point for estimating power plant construction costs because it avoids the consideration of financing the project. The above overnight power plant costs were developed for AEO2011.

The present value of the cost of capacity additions over the period 2013-2035 was calculated for the potential standards cases for GSFLs and the base case using a discount rate of five percent.^d A reduction of the net present value of the cost of capacity additions in the standards case is a positive avoided capacity benefit.

The avoided capacity benefit may result from reducing overall capacity additions compared to the base case or from delaying capacity additions. The delay in capacity additions can be isolated by adding the reduction in capacity additions from the standard to the end of the time series for standards case capacity additions. This new time series will then have the same total capacity additions as the base case while modeling the effect of the standard. The present value of this new time series will be representative of delayed capacity additions from the

^d Although the standards for GSFLs would take effect in 2017, the power sector module in NEMS shows some changes in electric capacity in the standards case prior to 2017.

standard. Delaying capacity additions reduces the present value of expenditures because of the time value of money.

Table 16.4.2 shows the present value of the reduction in the cost of future capacity additions associated with each of the considered TSLs.

Table 16.4.2 Present Value of Reduced Costs of Electricity Generation Capacity Addition Due to GSFL Standards*

TSL	Billion, 2012\$
1	0.02
2	0.02
3	0.09
4	0.35
5	0.41

*Includes both delayed and reduced capacity impacts

Although delayed investment implies a savings in total cost, because the delay may also cause increases in other costs, the savings may be less than the savings in capital cost. For example, if the delayed investment was the replacement of an existing facility with a larger, more efficient facility, the increased cost of operating the old facility during the period of delay might offset much of the savings from delayed investment. That the project was delayed is evidence that doing so decreased overall cost, but it does not indicate that the decrease was equal to the entire savings in capital cost.

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- ² Coughlin, K., H. Shen, P. Chan, B. McDevitt, and A. Sturges, Marginal Utility Sector Impacts of Reduced Electricity Demand, 2012.

CHAPTER 17. EMPLOYMENT IMPACT ANALYSIS

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CHAPTER 17. EMPLOYMENT IMPACT ANALYSIS

17.1 INTRODUCTION

DOE's employment impact analysis is designed to estimate indirect national job creation or elimination resulting from possible standards, due to reallocation of the associated expenditures for purchasing and operating lamps. Job increases or decreases reported in this chapter are separate from the direct lamp production sector employment impacts reported in the manufacturer impact analysis (Chapter 13), and reflect the employment impact of efficiency standards on all other sectors of the economy.

17.2 ASSUMPTIONS

DOE expects energy conservation standards to decrease energy consumption, and therefore to reduce energy expenditures. The savings in energy expenditures may be spent on new investment or not at all (*i.e.*, they may remain "saved"). The standards may increase the purchase price of products, including the retail price plus sales tax, and increase installation costs.

The ImSET input/output econometric model of the U.S. economy, this analysis estimated the short-term effect of these expenditure impacts on net economic output and employment. DOE intends this analysis to quantify the indirect employment impacts of these expenditure changes. It evaluated direct employment impacts at manufacturers' facilities in the manufacturer impact analysis (see Chapter 13).

DOE notes that ImSET is not a general equilibrium forecasting model, and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis.¹ Because ImSET does not incorporate price changes, the employment effects predicted by ImSET would over-estimate the magnitude of actual job impacts over the long run for this rule. Since input/output models do not allow prices to bring markets into equilibrium, they are best used for short-run analysis. DOE therefore includes a qualitative discussion of how labor markets are likely to respond in the longer term. In future rulemakings, DOE may consider the use of other modeling approaches for examining long run employment impacts.

17.3 METHODOLOGY

DOE bases its analysis on an input/output model of the U.S. economy that estimates the effects of standards on major sectors of the economy related to buildings and the net impact of standards on jobs. The Pacific Northwest National Laboratory developed the model, ImSET 3.1.1² (Impact of Sector Energy Technologies) as a successor to ImBuild³, a special-purpose version of the IMPLAN⁴ national input/output model. ImSET estimates the employment and income effects of building energy technologies. In comparison with simple economic multiplier

approaches, ImSET allows for more complete and automated analysis of the economic impacts of energy-efficiency investments in buildings.

In an input/output model, the level of employment in an economy is determined by the relationship of different sectors of the economy and the spending flows among them. Different sectors have different levels of labor intensity and so changes in the level of spending (*e.g.*, due to the effects of an efficiency standard) in one sector of the economy will affect flows in other sectors, which affects the overall level of employment.

ImSET uses a 187-sector model of the national economy to predict the economic effects of residential and commercial buildings technologies. ImSET collects estimates of initial investments, energy savings, and economic activity associated with spending the savings resulting from standards (*e.g.*, changes in final demand in personal consumption, business investment and spending, and government spending). It provides overall estimates of the change in national output for each input-output sector. The model applies estimates of employment and wage income per dollar of economic output for each sector and calculates impacts on national employment and wage income.

Energy-efficiency technology primarily affects the U.S. economy along three spending pathways. First, general investment funds are diverted to sectors that manufacture, install, and maintain energy-efficient products. The increased cost of products leads to higher employment in the product manufacturing sectors and lower employment in other economic sectors. Second, commercial firm and residential spending are redirected from utilities toward firms that supply production inputs. Third, electric utility sector investment funds are released for use in other sectors of the economy. When consumers use less energy, electric utilities experience relative reductions in demand which leads to reductions in utility sector investment and employment.

DOE also notes that the employment impacts estimated with ImSET for the entire economy differ from the employment impacts in the lamp manufacturing sector estimated in Chapter 13 using the Government Regulatory Impact Model (GRIM). The methodologies used and the sectors analyzed in the ImSET and GRIM models are different.

17.4 SHORT-TERM RESULTS

The results in this section refer to impacts of lamp standards relative to the base case. DOE disaggregated the impact of standards on employment into three component effects: increased capital investment costs, decreased energy costs, and changes in operations and maintenance costs. DOE presents the summary impact.

Conceptually, one can consider the impact of the rule in its first year on three aggregate sectors, the lamp production sector, the energy generation sector, and the general consumer goods sector (as mentioned above ImSET's calculations are made at a much more disaggregate level). By raising energy efficiency, the rule generally increases the purchase price of lamps; this increase in expenditures causes an increase in employment in this sector. At the same time, the improvements in energy efficiency reduce consumer expenditures on electricity, freeing up this money to be spent in other sectors. The reduction in electricity demand causes a reduction in

employment in that sector. Finally, based on the net impact of increased expenditures on lamps and reduced expenditures on electricity, consumer expenditures on everything else are either positively or negatively affected, increasing or reducing jobs in that sector accordingly. The model also captures any indirect jobs created or lost by changes in consumption due to changes in employment (e.g. as more workers are hired they consume more goods, which generates more employment; the converse is true for workers laid off).

Table 17.4.1 presents the modeled net employment impact from the rule in 2017 and 2022, rounded to the nearest hundred jobs. Approximately 74% of GSFL and 48% of IRL are domestically produced; 26% of GSFL and 52% of IRL are imported. The net employment impact estimate is sensitive to assumptions regarding the return to the U.S. economy of money spent on imported lamps. The two scenarios bounding the ranges presented in Table 17.4.1 represent situations in which none of the money spent on imported lamps returns to the U.S. economy and all of the money spent on imported lamps returns to the U.S. economy. The U.S. trade deficit in recent years suggests that between 50% and 75% of the money spent on imported lamps is likely to return, with employment impacts falling within the ranges presented below.

Table 17.4.1 Net National Short-term Change in Employment (Number of Jobs)

Product	Trial Standard Level	2017	2022
GSFL	TSL 1	-600 to -200	-100 to 200
	TSL 2	-600 to -200	-200 to 200
	TSL 3	-1,700 to -600	400 to 1,400
	TSL 4	-4,400 to -1,300	2,500 to 5,100
	TSL 5	-4,800 to -1,400	2,700 to 5,600
IRL	TSL 1	-100 to 0	100 to 400

For context, the Office of Management of Budget currently assumes that the unemployment rate may decline to 6.9% in 2014 and drop further to 5.3% in 2017.⁵ The unemployment rate in 2017 is projected to be close to “full employment.” When an economy is at full employment any effects on net employment are likely to be transitory as workers change jobs, rather than enter or exit longer-term employment.

17.5 LONG-TERM RESULTS

Over the long term DOE expects the energy savings to consumers to increasingly dominate the increase in product costs, resulting in increased aggregate savings to consumers. As a result, DOE expects demand for electricity to decline over time and demand for other goods to increase. Since the electricity generation sector is relatively capital intensive compared to the consumer goods sector, the net effect will be an increase in labor demand. In equilibrium, this should lead to upward pressure on wages and a shift in employment away from electricity generation towards consumer goods. Note that in long-run equilibrium there is no net effect on total employment since wages adjust to bring the labor market into equilibrium. Nonetheless, even to the extent that markets are slow to adjust, DOE anticipates that net labor market impacts will in general be negligible over time due to the small magnitude of the short-term effects

presented in Table 17.4.1. The ImSET model projections, assuming no price or wage effects until 2022, are included in the second column of Table 17.4.1.

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CHAPTER 18. REGULATORY IMPACT ANALYSIS

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CHAPTER 18. REGULATORY IMPACT ANALYSIS

18.1 INTRODUCTION

The U.S. Department of Energy (DOE) has determined that energy conservation standards for consumers of General Service Fluorescent Lamps (GSFLs) and Incandescent Reflector Lamps constitute an “economically significant regulatory action” under Executive Order (E.O.) 12866, Regulatory Planning and Review. 58 FR 51735 (October 4, 1993). This Regulatory Impact Analysis (RIA), which DOE has prepared pursuant to E.O. 12866, evaluates potential non-regulatory alternatives for two types of GSFLs, namely T8 4-ft Medium Bipin and T5 Miniature Bipin (MiniBP) Standard Output. The remaining four GSFL lamp types did not make up a large enough percentage of shipments to warrant analysis in this RIA. Further, DOE was unable to locate data specific to IRL and therefore did not analyze the impacts of non-regulatory policy alternatives for those lamps. This RIA compares the costs and benefits of each non-regulatory alternative to the costs and benefits associated with lamps of the two selected types of GSFLs, with same efficiency level as those of the proposed standards. 58 FR 51735, 51741.

For this analysis, DOE used an integrated National Impact Analysis (NIA)-RIA model built on the NIA model discussed in Chapter 12 for its analysis.

DOE identified six non-regulatory policy alternatives that possibly could provide incentives for the same energy efficiency levels as the ones in the proposed trial standard level (TSL) for the two selected types of GSFL. The non-regulatory policy alternatives are listed in Table 18.1.1. DOE evaluated each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and compared the effectiveness of each to the effectiveness of standards set for the selected types of GSFLs at the same level as the proposed standard.

Table 18.1.1 Non-Regulatory Alternatives to National Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

Sections 18.2 and 18.3 discuss the analysis of the six selected policies listed above (excluding the alternative of No New Regulatory Action). Section 18.4 presents the results of the policy alternatives.

18.2 NON-REGULATORY POLICIES

This section describes the method DOE used to analyze the energy savings and cost effectiveness of the non-regulatory policy alternatives for the two selected lamp types. This section also describes the assumptions underlying the analysis.

18.2.1 Methodology

DOE used its integrated NIA-RIA spreadsheet model to calculate the national energy savings (NES) and net present value (NPV) associated with each non-regulatory policy alternative. Chapter 12 of the technical support document (TSD) describes the NIA spreadsheet model. Appendix 18A discusses the NIA-RIA integrated model approach.

DOE quantified the effect of each alternative on the purchase of lamps that meet the efficiency levels corresponding to the proposed TSL. After establishing the quantitative assumptions underlying each alternative, DOE appropriately revised inputs to the NIA-RIA spreadsheet model. The primary model inputs revised were market shares of lamps meeting the target efficiency levels set for the proposed TSL. The shipments of lamps for any given year reflect a distribution of efficiency levels. DOE assumed, for the proposed TSL, that new energy efficiency standards would affect 100 percent of the shipments of lamps that did not meet the proposed TSL target level in the base case,^a whereas the non-regulatory policies would affect a smaller percentage of those shipments. DOE made certain assumptions about the percentage of shipments affected by each alternative policy. DOE used those percentages to calculate the shipment-weighted average energy consumption and costs of GSFLs attributable to each policy alternative.

Increasing the efficiency of energy consuming devices often increases their average installed cost. However, operating costs generally decrease because energy consumption declines. DOE therefore calculated an NPV for each non-regulatory alternative in the same way it did for the proposed standards. In some policy scenarios, increases in total installed cost are mitigated by government rebates or tax credits. Because DOE assumed that consumers would repay credits and rebates in some way (such as additional taxes), DOE did not include rebates or tax credits as a consumer benefit when calculating national NPV. DOE's analysis also excluded any administrative costs for the non-regulatory policies; including such costs would decrease the NPVs slightly.

The following are key measures for evaluating the impact of each alternative.

- National Energy Savings (NES), given in quadrillion Btus (quads), describes the cumulative national primary energy saved over the lifetime of lamps purchased during the 30-year analysis period starting in the effective date of the policy (2017-2046).

^a The base case for the NIA is a market-weighted average energy efficiency calculated from units at several efficiency levels.

- Net Present Value (NPV), represents the value of net monetary savings in 2013, expressed in 2012\$, from lamps purchased during the 30-year analysis period starting in the effective date of the policy (2017-2046). DOE calculated the NPV as the difference between the present value of installed cost and operating expenditures in the base case and the present value of those costs in each policy case. DOE calculated operating expenses (including energy costs) for the life of a lamp.

18.2.2 Assumptions Regarding Non-Regulatory Policies

The effects of non-regulatory policies are by nature uncertain because they depend on program implementation, marketing efforts, and on consumers' responses to a program. Because the projected effects depend on assumptions regarding the rate of consumer participation, they are subject to more uncertainty than are the impacts of mandatory standards, which DOE assumes will meet with full compliance. To increase the robustness of the analysis, DOE conducted a literature review regarding each non-regulatory policy and consulted with recognized experts to gather information on similar incentive programs that have been implemented in the United States. By studying experiences with the various types of programs, DOE sought to make credible assumptions regarding potential market impacts. Section 18.3 presents the sources DOE relied on in developing assumptions about each alternative policy and reports DOE's conclusions as they affected the assumptions that underlie the modeling of each alternative policy.

Each non-regulatory policy that DOE considered would improve the average efficiency of new GSFLs relative to their base case efficiency scenario (which involves no new regulatory action). The analysis considered that each alternative policy would induce consumers to purchase lamps having the same efficiency level as required by the proposed standards (the target level) set for TSL 5. As opposed to the standards case, however, the non-regulatory policy cases may not lead to 100 percent market penetration of lamps that meet the target level. Table 18.2.1 shows the efficiency level stipulated in the proposed standards for GSFLs. DOE assumed that the effects of non-regulatory policies would last for the whole analysis period (2017-2046).

Table 18.2.1 Efficiency Levels for the Proposed Trial Standard Level for GSFL Lamp Types

Lamp Type	Proposed Standard (TSL 5)	Representative Products	
	Lamp Efficacy (lm/W)	Lamp Efficacy (lm/W)	ANSI Rated Wattage (TSL 5)
T8 4-ft Medium Bipin	92.4	95.4	32.5 W
		96.0	28.4 W
		93.0	26.6 W
T5 MiniBP Standard Output	97.1	109.7	27.8 W
		111.5	26.0 W
		116.0	25.0 W

18.2.3 Policy Interactions

DOE calculated the effects of each non-regulatory policy separately from those of the other policies. In practice, some policies are most effective when implemented in combination, such as voluntary efficiency targets implemented with consumer rebates or tax credits. However, DOE attempted to make conservative assumptions to avoid double-counting policy impacts. The resulting policy impacts are not additive, and the combined effect of several or all policies cannot be inferred from summing their results.

Section 18.4 presents graphs that show the market penetration estimated under each non-regulatory policy for the selected GSFL lamp types.

18.3 NON-REGULATORY POLICY ASSUMPTIONS

The following subsections describe DOE's analysis of the impacts of the six non-regulatory policy alternatives to proposed standards for GSFLs. (Because the alternative of No New Regulatory Action has no energy or economic impacts, essentially representing the NIA base case, DOE did not perform any additional analysis for that alternative.) DOE developed estimates of the market penetration of high-efficiency lamps both with and without each of the non-regulatory policy alternatives.

18.3.1 No New Regulatory Action

The case in which no new regulatory action is taken with regard to the energy efficiency of GSFLs constitutes the base case, as described in Chapter 12, National Impact Analysis. The base case provides the basis of comparison for all other policies. By definition, no new regulatory action yields zero NES and an NPV of zero dollars.

18.3.2 Consumer Rebates

DOE considered the scenario in which the Federal government would provide financial incentives in the form of rebates to consumers for purchasing energy-efficient lamps. This policy provides a consumer rebate for purchasing GSFLs that operate at (or above) the same efficiency as stipulated in the proposed TSL (target level).

18.3.2.1 Methodology

DOE based its evaluation methodology for consumer rebates on a comprehensive study of California's potential for achieving energy efficiency. The study, performed by XENERGY, Inc.,^b summarized experiences with various utility rebate programs.¹ XENERGY's analytical method utilized graphs, or penetration curves, that estimate the market penetration of a technology based on its benefit/cost (B/C) ratio. DOE consulted with experts and reviewed other methods of estimating the effect of consumer rebate programs on the market penetration of efficient technologies. The other methods, developed after the referenced XENERGY report was published,^{2, 3, 4, 5, 6, 7} used different approaches: other economic parameters (e.g., payback period), expert surveys, or model calibration based on specific utility program data rather than multi-utility data. Some models in use by energy efficiency program evaluation experts were so client-specific that generic relationships between economic parameters and consumer response could not be established.⁵ DOE decided that the most appropriate available method for this RIA analysis was the XENERGY approach of penetration curves based on B/C ratio, which incorporates lifetime operating cost savings.

XENERGY's model estimates market impacts induced by financial incentives based on the premise that two types of information diffusion drive the adoption of new technologies. *Internal sources* of information encourage consumers to purchase new equipment primarily through word-of-mouth from early adopters. *External sources* affect consumer purchase decisions through marketing efforts and information from outside the consumer group. Appendix 18A contains additional details on internal and external information diffusion.

XENERGY's model equation accounts for the influences of both internal and external sources of information by superimposing the two components. Combining the two mechanisms for information diffusion, XENERGY's model generates a set of penetration (or implementation) curves for a policy measure. XENERGY calibrated the curves based on participation data from utility rebate programs. The curves illustrate the increased penetration (i.e., increased market share) of efficient equipment driven by consumer response to changes in B/C ratio induced by rebate programs. The penetration curves depict various diffusion patterns based on perceived market barriers (from no-barriers to extremely-high-barriers) to consumer purchase of high-efficiency equipment. DOE adjusted the XENERGY former penetration curves based on expert advice founded on more recent utility program experience.^{5, 8}

^b XENERGY is now owned by KEMA, Inc. (www.kema.com)

DOE modeled the effects of a consumer rebate policy for GSFLs by determining, for the proposed TSL, the increase in market penetration of lamps meeting the target level relative to their market penetration in the base case. It used the interpolation method presented in Blum et al (2011)⁹ to create customized penetration curves based on relationships between actual base case market penetrations and actual B/C ratios. To inform its estimate of B/C ratios provided by a rebate program DOE performed a thorough nationwide search for existing rebate programs for GSFLs. It gathered data on utility or agency rebates throughout the nation for these lamps, and used this data to calibrate the customized penetration curves it developed for T8 4-ft Medium Bipin and T5 MiniBP Standard Output GSFLs so they best reflect the market barrier level faced by each lamp type. Section 18.3.2.2 shows the interpolated curves used in the analysis.

18.3.2.2 Analysis

For the two GSFL lamp types it analyzed, DOE estimated the effect of increasing its B/C ratio via a rebate that would pay part of the increased installed cost of a lamp that met the target efficiency level compared to one meeting the baseline efficiency level.^c To inform its estimate of an appropriate rebate amount, DOE performed a thorough nationwide search for existing rebate programs for GSFLs. It gathered data from a sample of utility and agency rebate programs that includes 30 rebates for GSFLs initiated by 19 utilities or agencies in various States. (Appendix 18A, identifies the rebate programs.) To represent the rebate level for each lamp type analyzed in this RIA, DOE performed statistical analysis of the rebate amounts offered by these programs. DOE assumed that rebates would remain in effect at the same levels throughout the projection period (2017–2046).

For each of the two GSFL lamp types, DOE first calculated the B/C ratio without a rebate using the difference in total installed costs (C) and lifetime operating cost savings (B) between lamps meeting the target level and the baseline. It then calculated the B/C ratio given a rebate for lamps meeting the target efficiency level. Because the rebate reduced the incremental cost, lamps receiving the rebate had a larger B/C ratio. Table 18.3.1 shows the effect of consumer rebates on the B/C ratio for the proposed TSL.

^c The baseline technology for each lamp type is defined in the engineering analysis, Chapter 5, as the technology that represents the basic characteristics of lamps of that type. A baseline unit typically is one that just meets current Federal energy conservation standards and provides basic consumer utility.

Table 18.3.1 Benefit/Cost Ratios Without and With Rebates for General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
B/C Ratio Without Rebate	3.1
Rebate Amount (2012\$)	0.92
B/C Ratio With Rebate	4.1
Calculated Market Barriers Curve	Low - Moderate
T5 MiniBP Standard Output	
B/C Ratio Without Rebate	0.7
Rebate Amount (2012\$)	0.85
B/C Ratio With Rebate	0.9
Calculated Market Barriers Curve	No - Low

DOE used these B/C ratios along with the penetration curves shown in Figure 18.3.1 and Figure 18.3.2 to estimate the percentage of consumers who would purchase GSFLs that meet the target level both with and without a rebate incentive. The penetration curves calculated by DOE to represent the market behavior for T8 4-ft Medium Bipin and T5 MiniBP Standard Output GSFLs at the proposed TSL are indicated in Table 18.3.1.

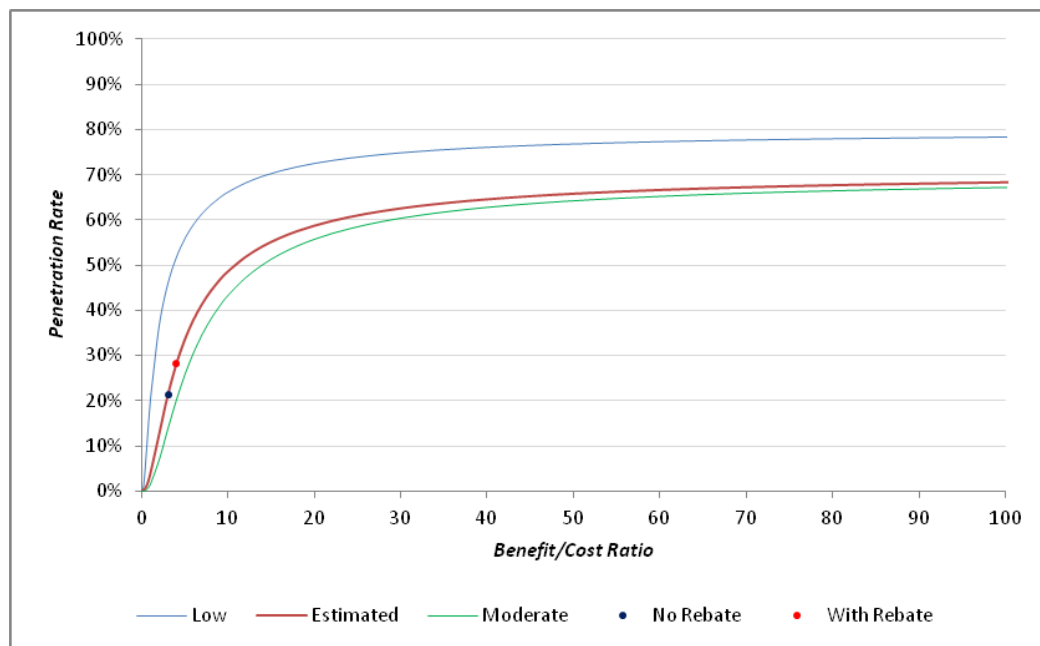


Figure 18.3.1 Market Penetration Curves for T8 4-ft Medium Bipin General Service Fluorescent Lamps

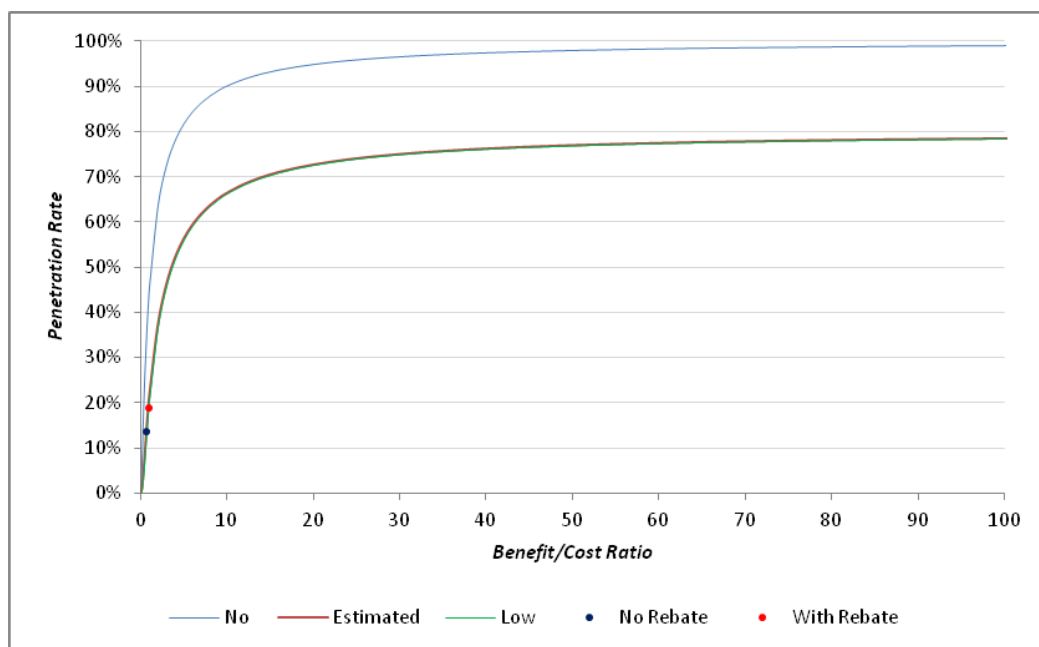


Figure 18.3.2 Market Penetration Curves for T5 MiniBP Standard Output General Service Fluorescent Lamps

For each lamp type, DOE next estimated the percent increases represented by the change in penetration rate shown on the corresponding penetration curve. It then added this percent increase to the market share of lamps that meet the target level in the base case to obtain the market share of lamps that meet the target level in the rebate policy case.

Table 18.3.2 summarizes DOE’s assumptions for GSFLs regarding the market penetration of lamps in 2017 that meet the target efficiency level given a consumer rebate.

Table 18.3.2 Market Penetrations in 2017 Attributable to Consumer Rebates for General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
Base-Case Market Share	21.4%
Policy Case Market Share	28.1%
Increased Market Share	6.8%
T5 MiniBP Standard Output	
Base-Case Market Share	13.7%
Policy Case Market Share	18.9%
Increased Market Share	5.2%

DOE used the resulting annual increases in market shares as inputs to represent the rebate policy case scenario in its NIA-RIA model. Appendix 18A shows the annual market share increases due to this policy. Section 18.4 presents the resulting market penetration trends for the policy case of consumer rebates for GSFLs.

18.3.3 Consumer Tax Credits

DOE estimated the effects of tax credits on consumer purchases based on its previous analysis of consumer participation in tax credits. DOE supported its approach using data from Oregon State's tax credit program for energy-efficient appliances. DOE also incorporated previous research that disaggregated the effect of rebates and tax credits into a *direct price effect*, which derives from the savings in purchase price, and an *announcement effect*, which is independent of the amount of the incentive.^{10, 11} The announcement effect derives from the credibility that a technology receives from being included in an incentive program, as well as changes in product marketing and modifications in markup and pricing. DOE assumed that the rebate and consumer tax credit policies would encompass both direct price effects and announcement effects, and that half the increase in market penetration associated with either policy would be due to the direct price effect and half to the announcement effect.

In estimating the effects of a tax credit on purchases of consumer products that meet new efficiency standards, DOE assumed the amount of the tax credit would be the same as the corresponding rebate amount discussed above.

DOE estimated that fewer consumers would participate in a tax credit program than would take advantage of a rebate. Research has shown that the delay required for a consumer to receive a tax credit, plus the added time and cost in preparing the tax return, make a tax credit incentive less effective than a rebate received at the time of purchase. Based on previous analyses, DOE assumed that only 60 percent of the consumers who would take advantage of a rebate would take advantage of a tax credit.¹²

In preparing its assumptions to estimate the effects of tax credits on consumer purchases of GSFLs, DOE also reviewed other tax credit programs that have been offered at both the Federal and State levels for energy-efficient appliances.

The Energy Policy Act of 2005 (EPACT 2005) included Federal tax credits for consumers who purchase energy-efficient products.¹³ Those tax credits were in effect in 2006 and 2007, expired in 2008, were reinstated for 2009–2010 by the American Recovery and Reinvestment Act of 2009 (ARRA), extended by Congress for 2011 with some modifications, and expired at the end of 2011.^{14, 15} The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.¹⁶ DOE reviewed Internal Revenue Service data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. However, DOE did not find data specific enough to GSFLs to warrant adjusting its analysis method for the Consumer Tax Credits policy case. Appendix 18A contains more information on Federal consumer tax credits.

DOE also reviewed its previous analysis of Oregon’s tax credits for clothes washers to provide support for its assumptions.¹⁷ In that previous analysis, DOE compared the market shares of ultra-high efficiency (UHE) residential clothes washers in Oregon, which offered both State tax credits and utility rebates, with those in Washington State, which offered only utility rebates during the same period. Based on this analysis, DOE estimated that in Oregon the impact of tax credits was 62 percent of the impact of rebates for UHE clothes washers having equivalent efficiency. This finding supports its original assumption that participation in a tax credit program would be about 60 percent of participation in a rebate program. Additional discussion of State tax credits for Oregon and other states is in Appendix 18A.

DOE applied the assumed 60 percent participation described above to the increase in penetration rates estimated for the rebate policy to estimate penetration rates attributable to consumer tax credits. In doing so, DOE incorporated the assumptions for consumer response to financial incentives from the penetration curves selected for GSFLs.

Table 18.3.3 summarizes DOE’s assumptions for GSFLs regarding the market penetration of lamps in 2017 that meet the target efficiency level given a consumer tax credit.

Table 18.3.3 Market Penetrations in 2017 Attributable to Consumer Tax Credits for General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
Base-Case Market Share	21.4%
Policy Case Market Share	25.4%
Increased Market Share	4.1%
T5 MiniBP Standard Output	
Base-Case Market Share	13.7%
Policy Case Market Share	16.8%
Increased Market Share	3.1%

The increased market shares attributable to consumer tax credits shown in Table 18.3.3 were used as inputs in the NIA-RIA model. Appendix 18A shows the annual market share increases due to this policy. Section 18.4 presents the resulting market penetration trends for the policy case of consumer tax credits for GSFLs that meet the efficiency level for the proposed TSL.

18.3.4 Manufacturer Tax Credits

To analyze the potential effects of a policy that offers tax credits to manufacturers that produce GSFLs that meet the target efficiency level at the proposed TSL, DOE assumed that a manufacturer tax credit would lower the consumer’s purchase cost by an amount equivalent to that provided by the consumer rebates or tax credits described above. DOE further assumed that

manufacturers would pass on some of their reduced costs to consumers, causing a direct price effect. DOE assumed that no announcement effect would occur, because the program would not be visible to consumers.^d Because the direct price effect is approximately equivalent to the announcement effect,¹⁰ DOE estimated that a manufacturer tax credit would induce half the number of consumers assumed to take advantage of a consumer tax credit to purchase more efficient lamps. Thus the assumed participation rate is equal to 30 percent of the number of consumers who would participate in a rebate program.

DOE attempted to investigate manufacturer response to the Energy Efficient Appliance Credits for manufacturers mandated by EPACT 2005.¹⁸ Those manufacturer tax credits have been in effect for dishwashers, clothes washers and refrigerators produced beginning in 2009. DOE was unable to locate data from the Internal Revenue Service or other sources on manufacturer response to the Federal credits. Appendix 18A presents details on Federal manufacturer tax credits.

DOE applied the assumption of 30 percent participation to the increase in penetration rates predicted for the rebate policy to estimate the effects of a manufacturer tax credit policy. In doing so, the Department incorporated the assumptions for consumer response to financial incentives from the penetration curves calculated for GSFLs.

Table 18.3.4 summarizes DOE's assumptions for GSFLs regarding the market penetration of lamps in 2017 meeting the efficiency level at the proposed TSL given a manufacturer tax credit.

Table 18.3.4 Market Penetrations in 2017 Attributable to Manufacturer Tax Credits for General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
Base-Case Market Share	21.4%
Policy Case Market Share	23.4%
Increased Market Share	2.0%
T5 MiniBP Standard Output	
Base-Case Market Share	13.7%
Policy Case Market Share	15.2%
Increased Market Share	1.6%

The increased market shares attributable to a manufacturer tax credit shown in Table 18.3.4 were used as inputs in the NIA-RIA model. Appendix 18A shows the annual market share

^d Note that this is a conservative assumption, since it is possible that manufacturers or utility/agency efficiency programs might promote the models for which manufacturers increase production due to the tax credits, which in turn might induce some announcement effect. However, DOE found no data on such programs on which to base an estimate of the magnitude of this possible announcement effect on consumer behavior.

increases due to this policy. Section 18.4 presents the resulting market penetration trends for the policy case of manufacturer tax credits for GSFLs.

18.3.5 Voluntary Energy Efficiency Targets

For each lamp type, DOE assumed that voluntary energy efficiency targets would be achieved as manufacturers gradually stopped producing lamps that operated below the efficiency level set for the proposed TSL. DOE assumed that the impetus for phasing out production of low-efficiency lamps would be a program similar to the ENERGY STAR labeling program conducted by the Environmental Protection Agency (EPA) and DOE. The ENERGY STAR program specifies the minimum energy efficiencies that various products must have to receive the ENERGY STAR label. ENERGY STAR encourages consumers to purchase efficient products via marketing that promotes consumer label recognition, various incentive programs that adopt the ENERGY STAR specifications, and manufacturers' promotion of their qualifying appliances. ENERGY STAR projects market penetration of compliant appliances and estimates the percentage of sales of compliant appliances that are attributable to the ENERGY STAR program.

Researchers have analyzed the ENERGY STAR program's effects on sales of several consumer products. Program efforts generally involve a combination of information dissemination and utility or agency rebates. The analyses have been based on State-specific data on percentages of shipments of various appliances that meet ENERGY STAR specifications. The analyses generally have concluded that the market penetration of ENERGY STAR-qualifying appliances is higher in regions or States where ancillary promotional programs have been active.^{19, 20, 21}

DOE believes that informational incentive programs – like ENERGY STAR, or any other labeling program sponsored by industry or other organizations – are likely to reduce the market barriers to more efficient equipment over time. During the rebate analysis, when assessing the B/C ratio and market penetration in the base case for each lamp type, DOE observed that the market barriers for the two lamp types evaluated in this RIA are below moderate level. DOE estimates that voluntary energy efficiency targets could eliminate these barriers over 10 years, and followed the methodology presented by Blum et al (2011)⁹ to evaluate the effects that such a reduction in market barriers have on the market penetration of each GSFL lamp type. The methodology relies on interpolated market penetration curves to calculate – given a B/C ratio – how the market penetration of more efficient lamps increases as the market barrier level to those lamps decreases.

Table 18.3.5 summarizes DOE's assumptions for GSFLs regarding the market penetration of lamps in 2017 meeting the efficiency level at the proposed TSL given a voluntary energy efficiency target program.

Table 18.3.5 Market Penetrations in 2017 Attributable to Voluntary Energy Efficiency Targets for General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
Base-Case Market Share	21.4%
Policy Case Market Share	28.7%
Increased Market Share	7.3%
T5 MiniBP Standard Output	
Base-Case Market Share	13.7%
Policy Case Market Share	17.4%
Increased Market Share	3.7%

DOE estimated that a program developed in support of the voluntary energy efficiency targets policy would increase market shares of efficient lamps. Appendix 18A shows the annual market share increases due to this policy used as inputs to the NIA-RIA model. Section 18.4 presents the resulting market penetration trends for the policy case of voluntary energy efficiency targets for GSFLs.

18.3.6 Bulk Government Purchases

Bulk government purchases can lead to Federal, State, and local governments purchasing large quantities of equipment that meet the target efficiency level. Combining the market demands of multiple public sectors also can provide a market signal to manufacturers and vendors that some of their largest customers seek equipment that meet an efficiency target at favorable prices. Such a program also can induce “market pull,” whereby manufacturers and vendors would achieve economies of scale for high efficiency equipment.

Most of the previous bulk government purchase (procurement) initiatives at the Federal, State, and municipal levels have not tracked data on numbers of purchases or degree of compliance with procurement specifications. In many cases, procurement programs are decentralized, being part of larger State or regional initiatives. DOE based its assumptions regarding the effects of this policy on studies the Federal Energy Management Program (FEMP) performed regarding the savings potential of its procurement specifications for appliances and other equipment. FEMP, however, does not track purchasing data, because of the complex range of purchasing systems, large number of vendors, and so on. States, counties, and municipalities have demonstrated increasing interest and activity in “green purchasing.” Although many of the programs target office equipment, the growing infrastructure for developing and applying efficient purchasing specifications indicates that bulk government purchase programs are feasible.^{22, 23}

DOE assumed that government agencies would administer bulk purchasing programs for GSFLs. At the federal level, this type of program could modify FEMP procurement guidelines for GSFLs. Currently, FEMP is evaluating the market impacts from the 2012 fluorescent tube lamps minimum efficiency standards, and has temporarily suspended the energy efficiency requirements for fluorescent tube lamps until market distribution stabilizes.²⁴ DOE reviewed its

own previous research on the potential for market transformation through bulk government purchases. Its major study analyzed several scenarios based on the assumption that 20 percent of Federal equipment purchases in 2000 already incorporated energy efficiency requirements based on FEMP guidelines. One scenario in the DOE report showed energy efficient purchasing ramping up during 10 years from 20 percent to 80 percent of all Federal purchases.²⁵ Based on this study, DOE estimated that a bulk government purchase program instituted within a 10-year period would result in at least 80 percent of government-purchased GSFLs meeting target efficiency levels.

DOE assumed that bulk government purchases of GSFLs would affect the efficiency distribution of GSFL shipments to the subset of federal government-owned commercial buildings lit by fluorescent lamps. According to the 2003 Commercial Buildings Energy Consumption Survey (CBECS 2003)²⁶, this subset includes buildings used, for example, for public assembly and public order and safety, as well as for offices, education, food service, health care, lodging and other services. DOE used CBECS 2003 data to calculate the percentage of the total commercial floor space lit by fluorescent lamps that corresponds to federal government-owned buildings. The calculation resulted in 2 percent. DOE assumed that percentage as the share of the market to which this policy would apply.

DOE estimated that, starting in 2017, each year of a bulk government purchase policy would result in an increasing percent of shipments of federal government-purchased GSFLs beyond the base case would meet target efficiency levels set to the proposed TSL. DOE estimated that within 10 years (by the end of 2026), such a program would result in 80 percent of the GSFL market for federal government-owned commercial buildings meeting the target level. DOE modeled the bulk government purchase program assuming that the market share for each lamp type achieved in 2026 would be maintained throughout the rest of the analysis period.

Table 18.3.6 summarizes DOE's assumptions for GSFLs regarding the market penetration of lamps in 2017 that meet the target efficiency level at the proposed TSL given a bulk government purchasing program.

Table 18.3.6 Market Penetrations in 2017 Attributable to Bulk Government Purchasing of General Service Fluorescent Lamps

Lamp Type	Proposed Trial Standard Level (TSL 5)
T8 4-ft Medium Bipin	
Base-Case Market Share	21.4%
Market Share	21.5%
Increased Market Share	0.1%
T5 MiniBP Standard Output	
Base-Case Market Share	13.7%
Market Share	13.8%
Increased Market Share	0.1%

The increased market shares attributable to a bulk government purchasing program shown in Table 18.3.6 were used as inputs in the NIA-RIA model. Appendix 18A shows the annual market share increases due to this. Section 18.4 below presents the resulting market penetration trends for the policy case of bulk government purchase of GSFLs.

18.4 IMPACTS OF NON-REGULATORY ALTERNATIVES

Figure 18.4.1 and Figure 18.4.2 show the effects of each non-regulatory policy on market penetration for T8 4-ft Medium Bipin and T5 MiniBP Standard Output GSFLs. Relative to the base case, the policy cases increase the market shares that meet the target level. However, as mentioned above, the proposed standards (not shown in the figures) would result in a 100-percent market penetration of lamps that meet the target efficiency level.

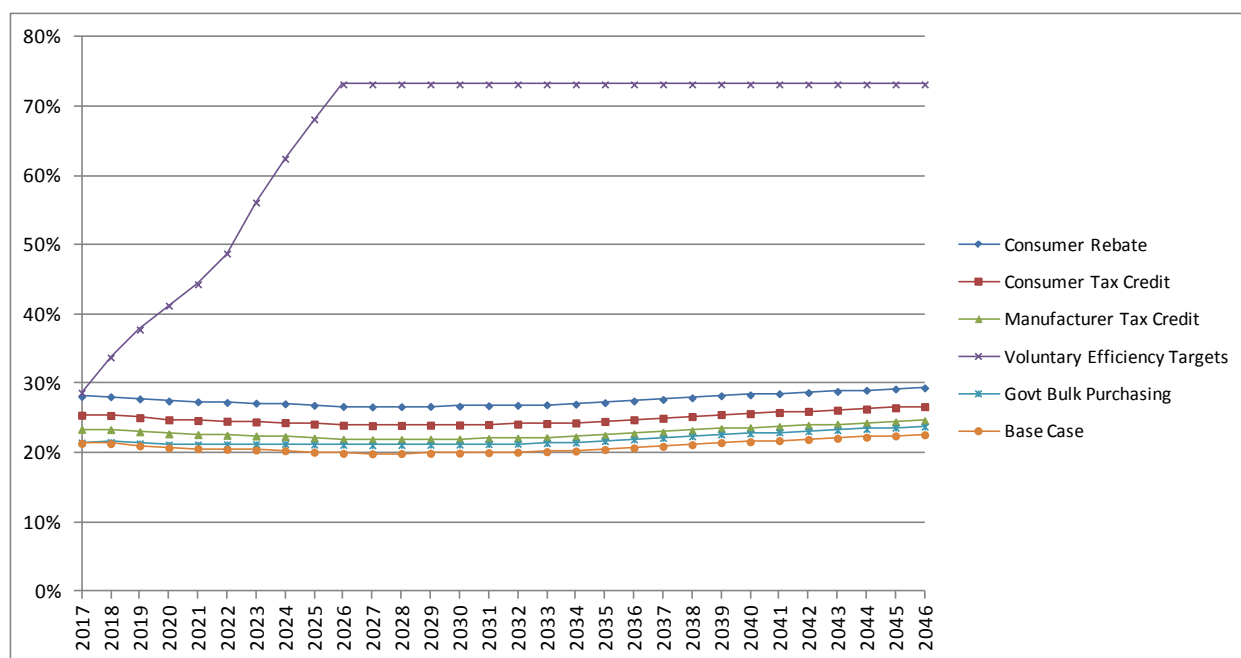


Figure 18.4.1 Market Penetration of T8 4-ft Medium Bipin General Service Fluorescent Lamps (TSL 5)

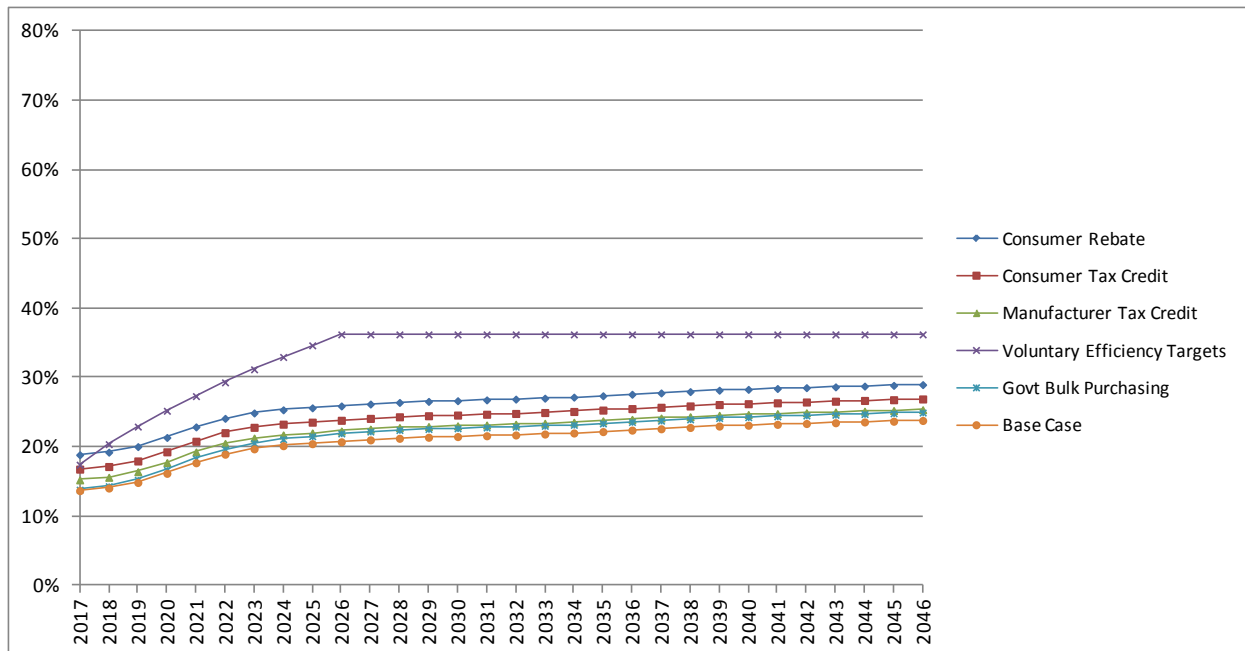


Figure 18.4.2 Market Penetration of T5 MiniBP Standard Output General Service Fluorescent Lamps(TSL 5)

Table 18.4.1 and Table 18.4.2 show the national energy savings and net present value for five non-regulatory policies analyzed in detail for GSFLs. The target level for each policy equals the efficiency levels proposed for standards in TSL 5. The case in which no regulatory action is taken with regard to GSFLs constitutes the base case (or "No New Regulatory Action" scenario), in which NES and NPV are zero by definition. Energy savings are given in quadrillion British thermal units (quads), and economic savings are based on two discount rates, 7 percent and 3 percent. For comparison, the tables include the impacts from standards set at the same efficiency levels as the ones set for the non-regulatory alternatives. Results from standards in Table 18.4.1 and Table 18.4.2, however, do not match the NIA NES and NPV results reported in Chapter 12. While the NIA evaluates energy and economic savings from both ballasts and lamps, this RIA focuses on lamps only and accounts for the energy and economic savings that result from shifting shipments of all GSFL lamps with efficiency level below the target level to the target level.

The policy with the highest projected cumulative energy savings is voluntary energy efficiency targets. Bulk government purchases, due to the small share of floor space lit by fluorescent lamps in federal government-owned buildings compared to all commercial buildings, have little impacts. All NPV results for T5 MiniBP Standard Output GSFLs are negative, which is consistent with results from the NIA.

Table 18.4.1 Impacts of Non-Regulatory Alternatives for T8 4-ft Medium Bipin General Service Fluorescent Lamps(TSL 5)

Policy Alternative	Primary Energy Savings <u>quads</u>	Net Present Value* <u>billion 2012\$</u>	
		7% Discount Rate	3% Discount Rate
Consumer Rebates	0.018	1.267	1.936
Consumer Tax Credits	0.011	0.760	1.162
Manufacturer Tax Credits	0.005	0.380	0.581
Voluntary Energy Efficiency Targets	0.102	5.891	10.002
Bulk Government Purchases	0.002	0.136	0.231
Standards**	0.213	14.867	22.721

* For lamps shipped 2018 – 2047.

** Standards calculated for shipments of lamps only.

Table 18.4.2 Impacts of Non-Regulatory Alternatives for T5 MiniBP Standard Output General Service Fluorescent Lamps (TSL 5)

Policy Alternative	Primary Energy Savings <u>quads</u>	Net Present Value* <u>billion 2012\$</u>	
		7% Discount Rate	3% Discount Rate
Consumer Rebates	0.003	-0.044	-0.067
Consumer Tax Credits	0.002	-0.026	-0.040
Manufacturer Tax Credits	0.001	-0.013	-0.020
Voluntary Energy Efficiency Targets	0.007	-0.088	-0.143
Bulk Government Purchases	0.000	-0.006	-0.010
Standards**	0.046	-0.700	-1.060

* For lamps shipped 2018 – 2047.

** Standards calculated for shipments of lamps only.

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APPENDIX AA. ACRONYMS AND ABBREVIATIONS

ACEEE	American Council for an Energy-Efficient Economy
ADLT	Advanced Lighting Technologies
AEC	Annual Energy Consumption
AEO	Annual Energy Outlook
AHS	American Housing Survey
AMOLED	Active-matrix organic light-emitting diode
ANSI	American National Standards Institute
ASAP	Appliance Standards Awareness Project
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASM	Annual Survey of Manufacturers
ASU	Air separation unit
BaO	Barium oxide
BF	Ballast factor
BLE	Ballast luminous efficiency
BLS	Bureau of Labor Statistics
BPAR	Bulged parabolic aluminum reflector
BR	Bulged reflector
CA IOUs	California investor-owned utilities, (PG&E), Southern California Gas Company including Pacific Gas and Electric Company (SCGC), San Diego Gas and Electric (SDG&E), and Southern California Edison (SCE)
CAIR	Clean Air Interstate Rule
CAPM	Capital asset pricing model
CaO	Calcium oxide
CAT	Computer axial tomography
CBCP	Center Beam Candle Power
CBECS	Commercial Buildings Energy Consumption Survey
CBSA	Commercial Building Stock Assessment
CC	Coiled coil
CCE	Certification, compliance, and enforcement
CCMS	Compliance Certification Management System
CCR	California Code of Regulations
CCT	Correlated color temperature
CEC	California Energy Commission
CEE	Consortium for Energy Efficiency
CFL	Compact fluorescent lamp
CFR	Code of Federal Regulations
CLC	Cape Light Compact
CIR	Current Industrial Reports
CMS	Critical Materials Strategy
CO ₂	Carbon dioxide
CO ₂ eq	Carbon dioxide equivalent
CoC	Certification of Conformity
CPI	Consumer Price Index

CRI	Color rendering index
CSAPR	Cross-State Air Pollution Rule
CSL	Candidate standard level
CT	Computed tomography
DOE	U.S. Department of Energy
DOJ	U.S. Department of Justice
EEI	Edison Electric Institute
EGU	Electric generating units
EIA	U.S. Energy Information Administration
EISA 2007	Energy Independence and Security Act of 2007
EL	Efficacy level
EMI	Electromagnetic interference
EPA	U.S. Environmental Protection Agency
EPAct 1992	Energy Policy Act of 1992
EPCA	Energy Policy and Conservation Act
ER	Elliptical reflector
ERP	Enterprise resource planning
EU	European Union
FEMP	Federal Energy Management Program
FFC	Full-fuel-cycle
FOB	Free-on-board
FTC	Federal Trade Commission
GE	General Electric
GHG	Greenhouse gas
GREET	Gases, Regulated Emissions, and Energy Use in Transportation
GRIM	Government Regulatory Impact Model
GSFL	General service fluorescent lamp
GSIL	General service incandescent lamp
GVEA	Golden Valley Electric Association
HAP	Hazardous air pollutants
Hg	Mercury
HID	High intensity discharge
HIR	Halogen infrared reflector
HO	High output
HSPD	Homeland Security Presidential Directive
IEC	International Electrotechnical Commission
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
IMERC	Interstate Mercury Education and Reduction Clearinghouse
ImSET	Impact of Sector Energy Technologies model
INPV	Industry net present value
IR	Infrared
IRL	Incandescent reflector lamp
IS	Instant start
K	Kelvin
LCC	Life-cycle cost

LCD	Liquid crystal display
LED	Light-emitting diode
LLMF	Lamp lumen maintenance factor
LMC	Lighting Market Characterization 2010
lm/W	Lumens per watt
LSF	Lamp survival factor
MATS	Mercury and Air Toxics Standards
Max tech	Maximum technologically feasible
MBP	Medium bipin
MECS	Manufacturer Energy Consumption Survey
MEMS	Micro-electro-mechanical systems
MIA	Manufacturer impact analysis
MiniBP	Miniature bipin
MPCs	Manufacturer production costs
MRI	Magnetic resonance images
MSP	Manufacturer selling price
NAICS	North American Industry Classification System
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NEMA	National Electrical Manufacturers Association
NEMS	National Energy Modeling System
NES	National energy savings
NIA	National impact analysis
NODA	Notice of data availability
NOM	Norma Oficial Mexicana
NOPM	Notice of public meeting
NOPR	Notice of proposed rulemaking
NO _x	Nitrogen oxides
NPCC	Northwest Power and Conservation Council
NPV	Net present value
NRCAN	Natural Resources Canada
NRDC	Natural Resources Defense Council
O&M	Operations and maintenance
OAL	Office of Administrative Law
OEE	Office of Energy Efficiency
OEM	Original equipment manufacturers
OHA	Office of Hearings and Appeals
OLED	Organic light-emitting diode
OMB	Office of Management and Budget
OSSDAP	Operating stock shipped during the analysis period
OSI	Osram Sylvania
PAR	Parabolic aluminized reflector
PBP	Payback period
PDP	Plasma display panels
PG&E	Pacific Gas and Electric
PM	Particulate matter

PNNL	Pacific Northwest National Laboratory
PPE	Plant, property, and equipment
PPI	Producer Price Index
PS	Programmed start
R&D	Research and development
RBSA	Residential Building Stock Assessment
RDC	Recessed double contact
RECS	Residential Energy Consumption Survey
REO	Rare earth oxide
RIA	Regulatory impact analysis
RIN	Regulatory information number
RLS	Residential Lighting Strategy
RoHS	Restriction of Hazardous Substance
ROI	Returns on investment
RS	Rapid start
S&P	Standard and Poor's
SASO	Saudi Arabian Standards Organization
SBA	Small Business Administration
SCC	Social Cost of Carbon
SCE	Southern California Edison
SCF	Survey of Consumer Finances
SCGC	Southern California Gas Company
SDG&E	San Diego Gas and Electric
SEC	Securities and Exchange Commission
SG&A	Selling, general, and administrative
SO	Standard output
SO ₂	Sulfur dioxide
SP	Single pin
SPD	Spectral power distribution
SSL	Solid-State Lighting
T-Bill	Treasury Bill
TSD	Technical support document
TSL	Trial standard level
U.S.C.	United States Code
UL	Underwriters Laboratories
UV	Ultraviolet
VHO	Very high output
WACC	Weighted average cost of capital

APPENDIX 3A. LIGHTING DEFINITIONS IN THE UNITED STATES CODE AND CODE OF FEDERAL REGULATIONS

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APPENDIX 3A. LIGHTING DEFINITIONS IN THE UNITED STATES CODE AND CODE OF FEDERAL REGULATIONS

3A.1 INTRODUCTION

Appendix 3A provides definitions from the United States Code (U.S.C.) and Code of Federal Regulations (CFR) for the lamp products covered under this rulemaking. (42 U.S.C. 6291(30); 10 CFR section 430.2) These definitions do not include fluorescent lamp definitions associated with fluorescent ballast standards.

3A.2 GENERAL SERVICE FLUORESCENT LAMPS

3A.2.1 United States Code Definitions

42 U.S.C. 6291(30)(A)

Except as provided in subparagraph (E), the term “fluorescent lamp” means a low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light, including only the following:

- (i) Any straight-shaped lamp (commonly referred to as 4-foot medium bi-pin lamps) with medium bi-pin bases of nominal overall length of 48 inches and rated wattage of 28 or more.*
- (ii) Any U-shaped lamp (commonly referred to as 2-foot U-shaped lamps) with medium bi-pin bases of nominal overall length between 22 and 25 inches and rated wattage of 28 or more.*
- (iii) Any rapid start lamp (commonly referred to as 8-foot high output lamps) with recessed double contact bases of nominal overall length of 96 inches and 0.800 nominal amperes, as defined in ANSI C78.1–1978 and related supplements.*
- (iv) Any instant start lamp (commonly referred to as 8-foot slimline lamps) with single pin bases of nominal overall length of 96 inches and rated wattage of 52 or more, as defined in ANSI C78.3–1978 (R1984) and related supplement ANSI C78.3a–1985*

42 U.S.C. 6291(30)(E)

The terms “fluorescent lamp” and “incandescent lamp” do not include any lamp excluded by the Secretary, by rule, as a result of a determination that standards for such lamp would not result in significant energy savings because such lamp is designed for special applications or has special characteristics not available in reasonably substitutable lamp types.

42 U.S.C. 6291(30)(B)

The term “general service fluorescent lamp” means fluorescent lamps which can be used to satisfy the majority of fluorescent applications, but does not include any lamp designed and marketed for the following nongeneral lighting applications:

- (i) *Fluorescent lamps designed to promote plant growth.*
- (ii) *Fluorescent lamps specifically designed for cold temperature installations.*
- (iii) *Colored fluorescent lamps.*
- (iv) *Impact-resistant fluorescent lamps.*
- (v) *Reflectorized or aperture lamps.*
- (vi) *Fluorescent lamps designed for use in reprographic equipment.*
- (vii) *Lamps primarily designed to produce radiation in the ultra-violet region of the spectrum.*
- (viii) *Lamps with a color rendering index of 87 or greater.*

3A.2.2 Code of Federal Regulations Definitions in 10 CFR 430.2

Basic model means all units of a given type of covered product (or class thereof) manufactured by one manufacturer, having the same primary energy source, and which have essentially identical electrical, physical, and functional (or hydraulic) characteristics that affect energy consumption, energy efficiency, water consumption, or water efficiency; and

- (1) *With respect to general service fluorescent lamps, general service incandescent lamps, and incandescent reflector lamps: Lamps that have essentially identical light output and electrical characteristics—including lumens per watt (lm/W) and color rendering index (CRI).*

* * * * *

Cold temperature fluorescent lamp means a fluorescent lamp specifically designed to start at –20 °F when used with a ballast conforming to the requirements of ANSI C78.81 (incorporated by reference; see § 430.3) and ANSI C78.901 (incorporated by reference; see § 430.3), and is expressly designated as a cold temperature lamp both in markings on the lamp and in marketing materials, including catalogs, sales literature, and promotional material.

Colored fluorescent lamp means a fluorescent lamp designated and marketed as a colored lamp and not designed or marketed for general illumination applications with either of the following characteristics:

- (1) *A CRI less than 40, as determined according to the method set forth in CIE Publication 13.3 (incorporated by reference; see § 430.3); or*
- (2) *A correlated color temperature less than 2,500K or greater than 7,000K as determined according to the method set forth in IES LM-9 (incorporated by reference; see § 430.3).*

Fluorescent lamp means a low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light, including only the following:

- (1) *Any straight-shaped lamp (commonly referred to as 4-foot medium bipin lamps) with medium bipin bases of nominal overall length of 48 inches and rated wattage of 25 or more;*

- (2) Any U-shaped lamp (commonly referred to as 2-foot U-shaped lamps) with medium bipin bases of nominal overall length between 22 and 25 inches and rated wattage of 25 or more;
- (3) Any rapid start lamp (commonly referred to as 8-foot high output lamps) with recessed double contact bases of nominal overall length of 96 inches;
- (4) Any instant start lamp (commonly referred to as 8-foot slimline lamps) with single pin bases of nominal overall length of 96 inches and rated wattage of 52 or more;
- (5) Any straight-shaped lamp (commonly referred to as 4-foot miniature bipin standard output lamps) with miniature bipin bases of nominal overall length between 45 and 48 inches and rated wattage of 26 or more; and
- (6) Any straight-shaped lamp (commonly referred to as 4-foot miniature bipin high output lamps) with miniature bipin bases of nominal overall length between 45 and 48 inches and rated wattage of 49 or more.

Rated wattage means:

- (1) With respect to fluorescent lamps and general service fluorescent lamps:
 - (i) If the lamp is listed in ANSI C78.81 (incorporated by reference; see § 430.3) or ANSI C78.901 (incorporated by reference; see § 430.3), the rated wattage of a lamp determined by the lamp designation of Clause 11.1 of ANSI C78.81 or ANSI C78.901;
 - (ii) If the lamp is a residential straight-shaped lamp, and not listed in ANSI C78.81 (incorporated by reference; see § 430.3), the wattage of a lamp when operated on a reference ballast for which the lamp is designed; or
 - (iii) If the lamp is neither listed in one of the ANSI standards referenced in (1)(i) of this definition, nor a residential straight-shaped lamp, the electrical power of a lamp when measured according to the test procedures outlined in appendix R to subpart B of this part.

* * * * *

Residential straight-shaped lamp means a low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light, including a straight-shaped fluorescent lamp with medium bi-pin bases of nominal overall length of 48 inches and is either designed exclusively for residential applications; or designed primarily and marketed exclusively for residential applications.

- (1) A lamp is designed exclusively for residential applications if it will not function for more than 100 hours with a commercial high-power-factor ballast.
- (2) A lamp is designed primarily and marketed exclusively for residential applications if it:
 - (i) Is permanently and clearly marked as being for residential use only;
 - (ii) Has a life of 6,000 hours or less when used with a commercial high-power-factor ballast;
 - (iii) Is not labeled or represented as a replacement for a fluorescent lamp that is a covered product; and

- (iv) *Is marketed and distributed in a manner designed to minimize use of the lamp with commercial high-power-factor ballasts.*
- (3) *A manufacturer may market and distribute a lamp in a manner designed to minimize use of the lamp with commercial high-power-factor ballasts by:*
 - (i) *Packaging and labeling the lamp in a manner that clearly indicates the lamp is for residential use only and includes appropriate instructions concerning proper and improper use; if the lamp is included in a catalog or price list that also includes commercial/industrial lamps, listing the lamp in a separate residential section accompanied by notes about proper use on the same page; and providing as part of any express warranty accompanying the lamp that improper use voids such warranty; or*
 - (ii) *Using other comparably effective measures to minimize use with commercial high-power-factor ballasts.*

3A.3 INCANDESCENT REFLECTOR LAMPS

3A.3.1 United States Code Definitions

42 U.S.C. 6291(30)(C)

Except as provided in subparagraph (E), the term “incandescent lamp” means a lamp in which light is produced by a filament heated to incandescence by an electric current, including only the following:

- (i) *Any lamp (commonly referred to as lower wattage nonreflector general service lamps, including any tungsten-halogen lamp) that has a rated wattage between 30 and 199 watts, has an E26 medium screw base, has a rated voltage or voltage range that lies at least partially within 115 and 130 volts, and is not a reflector lamp.*
- (ii) *Any lamp (commonly referred to as a reflector lamp) which is not colored or designed for rough or vibration service applications, that contains an inner reflective coating on the outer bulb to direct the light, an R, PAR, ER, BR, BPAR, or similar bulb shapes with E26 medium screw bases, a rated voltage or voltage range that lies at least partially within 115 and 130 volts, a diameter which exceeds 2.25 inches, and has a rated wattage that is 40 watts or higher*
- (iii) *Any general service incandescent lamp (commonly referred to as a high- or higher-wattage lamp) that has a rated wattage above 199 watts (above 205 watts for a high wattage reflector lamp).*

42 U.S.C. 6291(30)(E)

The terms “fluorescent lamp” and “incandescent lamp” do not include any lamp excluded by the Secretary, by rule, as a result of a determination that standards for such lamp would not result in significant energy savings because such lamp is designed for special applications or has special characteristics not available in reasonably substitutable lamp types.

42 U.S.C. 6291(30)(F)

The term “incandescent reflector lamp” means a lamp described in subparagraph (C)(ii).

42 U.S.C. 6291(30)(I)

The term “bulb shape” means the shape of lamp, especially the glass bulb with designations for bulb shapes found in ANSI C79.1–1980 (R1984).

42 U.S.C. 6291(51)

The term “medium screw base” means an Edison screw base identified with the prefix E–26 in the “American National Standard for Electric Lamp Bases”, ANSI/IEC C81.61–2003, published by the American National Standards Institute.

42 U.S.C. 6291(54)

BPAR incandescent reflector lamp.—The term “BPAR incandescent reflector lamp” means a reflector lamp as shown in figure C78.21–278 on page 32 of ANSI C78.21–2003.

3A.3.2 Code of Federal Regulations Definitions in 10 CFR 430.2

Basic model means all units of a given type of covered product (or class thereof) manufactured by one manufacturer, having the same primary energy source, and which have essentially identical electrical, physical, and functional (or hydraulic) characteristics that affect energy consumption, energy efficiency, water consumption, or water efficiency; and

- (1) With respect to general service fluorescent lamps, general service incandescent lamps, and incandescent reflector lamps: Lamps that have essentially identical light output and electrical characteristics—including lumens per watt (lm/W) and color rendering index (CRI).*

* * * * *

Colored incandescent lamp means an incandescent lamp designated and marketed as a colored lamp that has—

- (1) A color rendering index of less than 50, as determined according to the test method given in CIE 13.3 (incorporated by reference; see § 430.3); or*
(2) A correlated color temperature of less than 2,500K, or greater than 4,600K, where correlated temperature is computed according to the “Computation of Correlated Color Temperature and Distribution Temperature,” Journal of the Optical Society of America, (incorporated by reference; see § 430.3).

Design voltage with respect to an incandescent lamp means:

- (1) The voltage marked as the intended operating voltage;*
(2) The mid-point of the voltage range if the lamp is marked with a voltage range; or
(3) 120 V if the lamp is not marked with a voltage or voltage range.

Incandescent lamp means a lamp in which light is produced by a filament heated to incandescence by an electric current, including only the following:

- (1) Any lamp (commonly referred to as lower wattage non-reflector general service lamps, including any tungsten halogen lamp) that has a rated wattage between 30 and 199, has an E26 medium screw base, has a rated voltage or voltage range that lies at least partially in the range of 115 and 130 volts, and is not a reflector lamp.*
- (2) Any incandescent reflector lamp.*
- (3) Any general service incandescent lamp (commonly referred to as a high-or higher-wattage lamp) that has a rated wattage above 199 (above 205 for a high wattage reflector lamp).*

Incandescent reflector lamp (commonly referred to as a reflector lamp) means any lamp in which light is produced by a filament heated to incandescence by an electric current, which: is not colored or designed for rough or vibration service applications that contains an inner reflective coating on the outer bulb to direct the light; has an R, PAR, ER, BR, BPAR, or similar bulb shapes with an E26 medium screw base; has a rated voltage or voltage range that lies at least partially in the range of 115 and 130 volts; has a diameter that exceeds 2.25 inches; and has a rated wattage that is 40 watts or higher.

Modified spectrum means, with respect to an incandescent lamp, an incandescent lamp that—

- (1) Is not a colored incandescent lamp; and*
- (2) When operated at the rated voltage and wattage of the incandescent lamp—*
 - (A) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies below the black-body locus; and*
 - (B) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies at least 4 MacAdam steps, as referenced in IESNA LM-16, distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.*

Rated voltage with respect to incandescent lamps means:

- (1) The design voltage if the design voltage is 115 V, 130 V or between 115V and 130 V;*
- (2) 115 V if the design voltage is less than 115 V and greater than or equal to 100 V and the lamp can operate at 115 V; and*
- (3) 130 V if the design voltage is greater than 130 V and less than or equal to 150 V and the lamp can operate at 130 V.*

Rated wattage means:

* * *

(2) *With respect to general service incandescent lamps and incandescent reflector lamps, the electrical power measured according to the test procedures outlined in appendix R to subpart B of this part.*

Rough or vibration service incandescent reflector lamp means a reflector lamp: in which a C-11 (5 support), C-17 (8 support), or C-22 (16 support) filament is mounted (the number of support excludes lead wires); in which the filament configuration is as shown in Chapter 6 of the 1993 Illuminating Engineering Society of North America Lighting Handbook, 8th Edition (see 10 CFR 430.22); and that is designated and marketed specifically for rough or vibration service applications.

Voltage range means a band of operating voltages as marked on an incandescent lamp, indicating that the lamp is designed to operate at any voltage within the band.

3A.4 ALL COVERED LAMPS

42 U.S.C. 6291(30)(G)

The term “average lamp efficacy” means the lamp efficacy readings taken over a statistically significant period of manufacture with the readings averaged over that period.

42 U.S.C. 6291(30)(H)

The term “base” means the portion of the lamp which connects with the socket as described in ANSI C81.61–1990.

42 U.S.C. 6291(30)(J)

The term “color rendering index” or “CRI” means the measure of the degree of color shift objects undergo when illuminated by a light source as compared with the color of those same objects when illuminated by a reference source of comparable color temperature.

42 U.S.C. 6291(30)(K)

The term “correlated color temperature” means the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source.

10 CFR 430.2

Lamp Efficacy (LE) means the measured lumen output of a lamp in lumens divided by the measured lamp electrical power input in watts expressed in units of lumens per watt (LPW).

42 U.S.C. 6291(30)(N)

The term “lamp type” means all lamps designated as having the same electrical and lighting characteristics and made by one manufacturer.

42 U.S.C. 6291(30)(O)

The term “lamp wattage” means the total electrical power consumed by a lamp in watts, after the initial seasoning period referenced in the appropriate IES standard test procedure and including, for fluorescent, arc watts plus cathode watts.

42 U.S.C. 6291(30)(P)

The terms “life” and “lifetime” mean length of operating time of a statistically large group of lamps between first use and failure of 50 percent of the group in accordance with test procedures described in the IES Lighting Handbook-Reference Volume.

42 U.S.C. 6291(30)(Q)

The term “lumen output” means total luminous flux (power) of a lamp in lumens, as measured in accordance with applicable IES standards as determined by the Secretary.

APPENDIX 5A. HIGHLY EFFICACIOUS INCANDESCENT REFLECTOR LAMPS

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APPENDIX 5A. HIGHLY EFFICACIOUS REFLECTOR LAMPS

5A.1 INTRODUCTION

As discussed in chapter 5 of this notice of proposed rulemaking (NOPR) technical support document (TSD), the U.S. Department of Energy (DOE) selects higher efficacy lamps as replacements for each baseline lamp identified in the engineering analysis. After identifying more efficacious substitutes, DOE develops efficacy levels (ELs). In conducting its analysis for the NOPR, DOE identified compliance information and also obtained prototype lamps that indicated it may be possible to achieve an efficacy level higher than EL 1. However, DOE did not have the necessary information to do a cost analysis to determine if an efficacy level based on these lamps would be economically justified. In the following sections, DOE provides an assessment of the information available regarding higher efficacy lamps and specifies the additional information it would need to analyze a higher efficacy level in a rulemaking analysis.

5A.2 BACKGROUND

In chapter 3 of this NOPR TSD, DOE discusses infrared (IR) glass coatings as a technology option. When a lamp contains an IR coating, it reflects emitted IR radiation back onto the filament, so if run at the same voltage, a lamp with an IR coating operates at a higher temperature. This increase in operating temperature increases light output, which in turn increases efficacy. DOE concluded that this technology met the required screening criteria outlined in chapter 4 of this NOPR TSD and considered it as a design option. The representative lamps analyzed at EL 1 in the engineering analysis (see chapter 5 of this NOPR TSD) utilize IR glass coatings to improve efficacy.

5A.3 HIGHER EFFICACY PRODUCTS

5A.3.1 Compliance Database

Information submitted to DOE's compliance database indicates that there may be lamps available at efficacies higher than EL 1. Firstech has submitted data indicating that 53 W PAR38 lamps with certified efficacies of 20.9 lm/W and 19.7 lm/W and lifetimes of 3,000 hours are achievable. However, DOE was unable to confirm the design options utilized in these lamps through interviews with manufacturers. DOE was also unable to obtain these lamps through the retail market to conduct efficacy testing.

5A.3.2 Prototype Lamps

During the public meeting for the preliminary analysis and through manufacturer interviews, DOE learned of the availability of high efficacy prototype IRLs. For the NOPR analysis, DOE obtained samples of these high efficacy prototype IRLs. Based on manufacturer interviews, DOE learned that the prototype lamps are able to achieve high efficacies by using an advanced IR coating. As mentioned earlier, an IR coating is a design option that is required to meet EL 1. An advanced IR coating uses a modified coating pattern and different materials to

increase the amount of light reflected back onto the filament, which in turn further increases lamp efficacy. Because IR coatings are already used in commercially available lamps, DOE does not believe that these lamps utilize a unique technology pathway to achieve higher efficacy.

DOE notes that although it was able to obtain them, the prototype lamps are not commercially available and were not manufactured during commercial scale production runs. Compliance information does not exist for these products at the time of this analysis.

5A.4 TESTING OF PROTOTYPE LAMPS

DOE obtained five samples each of three high-efficacy prototype models. DOE tested the efficacy of these lamps according to 10 CFR 430, subpart B, Appendix R and confirmed that their efficacies are higher than the efficacy required at EL 1. While DOE independently verified efficacy values, the manufacturer's testing for lifetime was still ongoing at the time of the NOPR analysis. Table 5A.4.1 presents the test results.

Table 5A.4.1 Test Results for IRL Prototype Lamps

Model	Sample Number	Wattage	Initial Light Output	Efficacy
		<i>W</i>	<i>lm</i>	<i>lm/W</i>
89PAR38/IR/FL25	1	89.4	2315	25.9
	2	87.3	1966	22.5
	3	88.2	2010	22.8
	4	86.7	2098	24.2
	5	86.4	2105	24.4
53PAR38/IR/FL25	6	53.4	1155	21.6
	7	52.5	1144	21.8
	8	53.2	1149	21.6
	9	53.6	1085	20.2
	10	53.5	1108	20.7
41PAR20/IR/FL25	11	41.9	834	19.9
	12	41.2	716	17.4
	13	40.7	770	18.9
	14	40.6	767	18.9
	15	40.4	750	18.6

The test results indicate that these lamps can achieve efficacies 10 to 16 percent higher than the maximum technological feasible (max tech) level analyzed in DOE's analysis. Thus, the measured efficacy of the prototype lamps exceeds the efficacy of commercially available lamps with similar lumen packages. DOE determined an efficacy level based on the test results for the prototype lamps. DOE's compliance requirements for IRLs require the reported efficacy to be the lower of the average efficacy or the lower confidence limit divided by 0.97 and a minimum sample size of 21 according to 10 CFR 429.27(a)(2)(i). DOE applied these requirements to the

test data using a sample size of five. Figure 5A.4.1 shows the resulting efficacy level (EL 2) which corresponds to an equation coefficient of 6.9 and would require advanced IR coatings to comply.

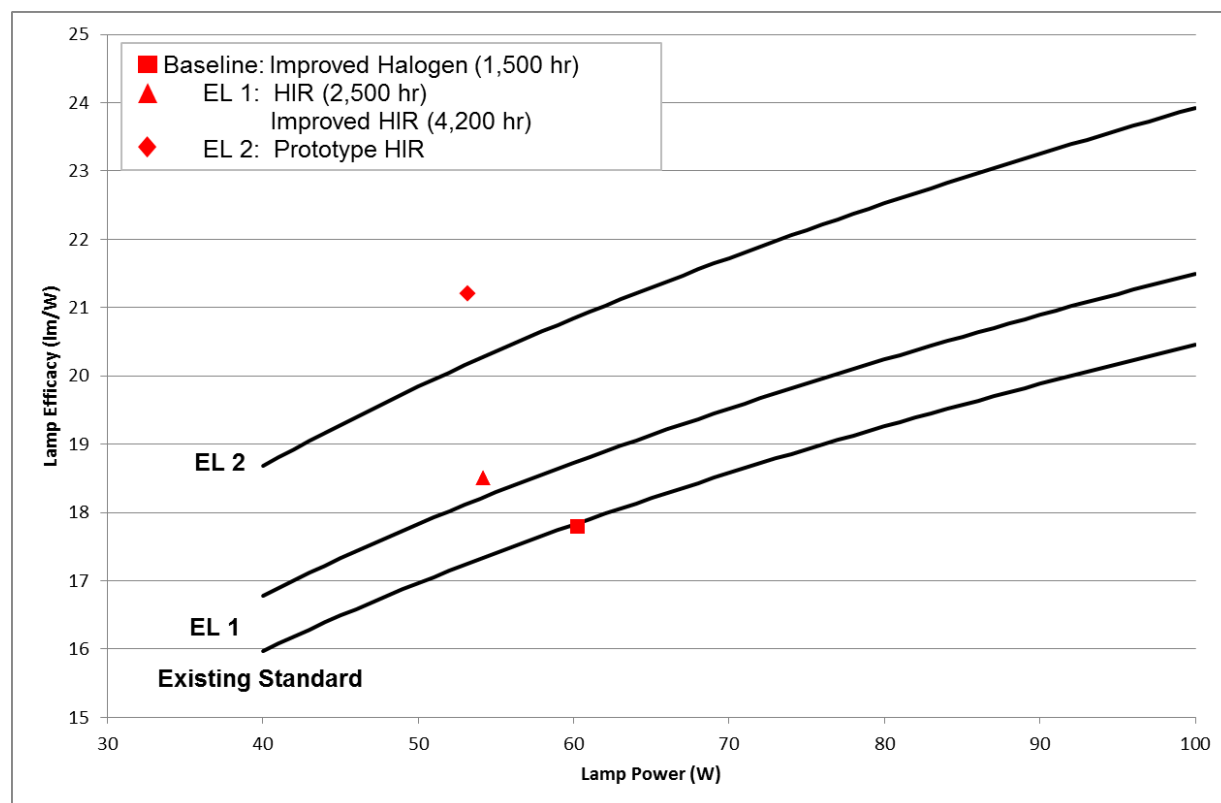


Figure 5A.4.1 NOPR Efficacy Levels and Efficacy of Prototype IRL

5A.5 PRICING

Although DOE was able to confirm efficacy values for the prototype lamps, DOE was unable to obtain information on their costs in order to include them in its analysis. These prototype lamps are not commercially available and therefore DOE was unable to identify retail prices for them. Other commercially available lamps did not achieve the same efficacy as the prototype models and DOE was therefore unable to obtain prices for equivalent products. Expected retail prices were provided through comments and manufacturer interviews, but the information indicated that the prices of the higher efficacy products would be less than those of the lamps that comply with EL 1.

DOE is seeking information on the cost to manufacture lamps that comply with EL 2 (shown above). Specifically, DOE is seeking information pertaining to the incremental manufacturer production cost of a lamp that complies with EL 2 compared to a lamp that complies with EL 1. DOE requests information to support any incremental cost provided.

5A.6 MANUFACTURER IMPACTS

As discussed previously, the prototype lamps achieve higher efficacies by using advanced IR coatings (i.e., more efficient IR coatings). IR coatings are also required to comply with EL 1. In interviews, manufacturers stated that if DOE were to adopt EL 1, they would need to invest in additional burner coating machines. Further, manufacturers expressed concern that to meet EL 1, they would be required to use IR coating technology from one company. Specifically, manufacturers stated that they would either need to purchase Advanced Lighting Technologies, Inc. (ADLT) coating machines or outsource coating of their burners to ADLT.

DOE is seeking information on whether the equipment required to apply IR coatings to lamps at EL 1 can be used to apply advanced IR coatings to lamps at EL 2. DOE is also seeking information on whether additional equipment, tooling, or other components are required to manufacture lamps that comply with EL 2. Finally, DOE requests information regarding product conversion costs (i.e. research, development, testing) that would be required and any other impacts that manufacturers would experience at EL 2.

5A.7 CONCLUSION

As shown in Table 5A.4.1, DOE has tested prototype lamps that indicate that it is possible to exceed the minimum efficacy required at EL 1. An advanced IR coating, which DOE believes is a technology available to all manufacturers, can likely be used to achieve an efficacy level (EL 2) higher than the max tech level analyzed in the NOPR analysis. To analyze EL 2, DOE is seeking information regarding the incremental manufacturer production cost of a lamp that complies with EL 2 and the impacts on manufacturers if DOE were to adopt this level.

APPENDIX 5B. MODIFIED SPECTRUM INCANDESCENT REFLECTOR LAMPS

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APPENDIX 5B. MODIFIED SPECTRUM INCANDESCENT REFLECTOR LAMPS

5B.1 INTRODUCTION

A *modified spectrum* incandescent lamp is an incandescent lamp with special coatings or other features that modify the wavelengths of light that exit the lamp, changing the perceived color of the lamp's light. These lamps are noticeably different in color than unmodified spectrum (or *standard spectrum*) incandescent lamps. Some incandescent reflector lamps (IRLs) are sold with features that modify their spectra, and the U.S. Department of Energy (DOE) believes that such IRLs provide a unique utility to users. For example, a number of these lamps are marketed as being able to reproduce the spectrum of natural daylight. The features that modify the spectra of incandescent lamps usually reduce the efficacies of the lamps. Thus, DOE created a modified spectrum IRL product class and established efficacy levels (ELs) for these lamps by scaling from ELs established for the standard spectrum IRL product classes. The same approach was taken in setting standards for modified spectrum IRLs in the first cycle of amendments to IRL standards published in a final rule in July 2009 (hereafter the "2009 Lamps Rule"). 74 FR 34080 (July 14, 2009).

In the 2009 Lamps Rule, DOE determined the scaling factor that should be applied to efficacy requirements for standard spectrum IRLs to establish efficacy requirements for modified spectrum IRLs. Using the definition of "modified spectrum" specified in Code of Federal Regulations (CFR), 10 CFR 430.2, DOE determined what lamps would be included in the modified spectrum IRL product class. DOE concluded in that rulemaking that the definition of modified spectrum was created for general service incandescent lamps (GSILs) because it requires the testing of clear lamps as a reference for spectrum comparison, and IRLs are not clear lamps due to their reflective coating. Therefore, DOE adapted the definition of "modified spectrum" for IRLs and developed the factor used to set the efficacy requirements for the modified spectrum IRL product class. In particular, DOE tested IRLs marketed as featuring spectral modification (such as lamps marketed as "daylight" lamps) and used similar standard spectrum IRLs as references for spectrum comparison. The following sections discuss the methodology used in the 2009 Lamps Rule to develop the scaling factor for the modified spectrum IRL product class.

5B.2 BACKGROUND

Objects absorb, reflect, and radiate a form of energy known as *electromagnetic radiation*, which can be visualized as waves of energy that travel through open space. Different wavelengths of electromagnetic radiation have different common names; for example, radio waves have wavelengths ranging from millimeters to hundreds of thousands of kilometers, and visible light has wavelengths roughly between 380 and 750 nanometers (nm). Various wavelengths of visible light are perceived as various colors by humans.

5B.2.1 Spectral Power Distribution and Commonly Used Color Properties

Some portion of the electromagnetic radiation emitted by lamps exists in the spectrum of visible light. Most lamps emit multiple wavelengths of light simultaneously, and the radiant

power (energy radiated per unit time) of each wavelength can be plotted as a spectral power distribution (SPD).¹ Example SPDs are shown in Figure 5B.2.1 for a specific standard spectrum IRL and a specific modified spectrum IRL tested for the 2009 Lamps Rule.

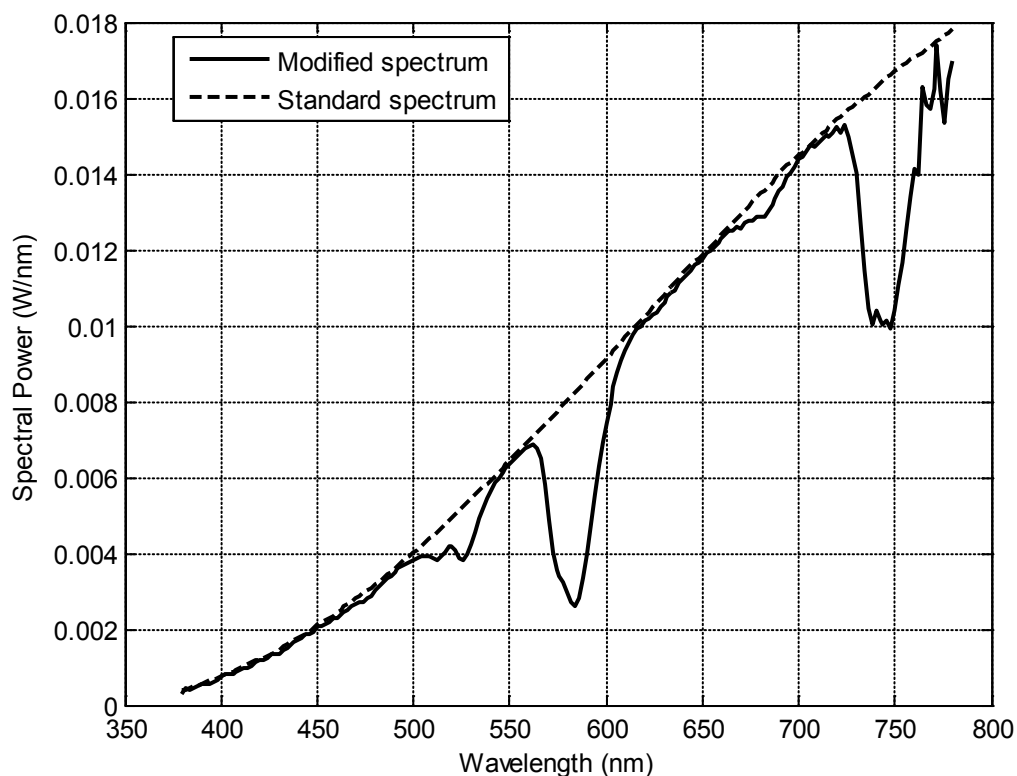


Figure 5B.2.1 Spectral Power Distribution of Two Tested IRLs

The measurement of a lamp's SPD allows the characterization of the lamp's perceived light color. Three color properties in particular are commonly computed for lamps based on the SPD. One is the *chromaticity*, which refers to the color of the lamp's light as indicated by a mapping onto a *chromaticity diagram* such as the Commission Internationale de l'Eclairage (C.I.E.) 1931 chromaticity diagram^a shown in Figure 5B.2.2.² Subtle differences in color can be quantified using *MacAdam steps*, named after David MacAdam, who studied color perception in the 1940s.³ A 3-step MacAdam ellipse is an ellipse that encircles a region of points on the chromaticity diagram that appear to be indistinguishable to most humans (in other words, they appear to be the same color). Points further than a distance of three MacAdam steps from any reference color point are generally perceived by most humans as being different in color than the reference point.

^a This particular figure is the chromaticity diagram for the CIE 1931 color space, created by the Commission Internationale de l'Eclairage (International Commission on Illumination, or CIE) in 1931. The colors on the outer curved boundary are composed of single wavelengths of electromagnetic radiation, with wavelengths indicated by the numbers. All colors inside the space are composed of a distribution of wavelengths of various powers.

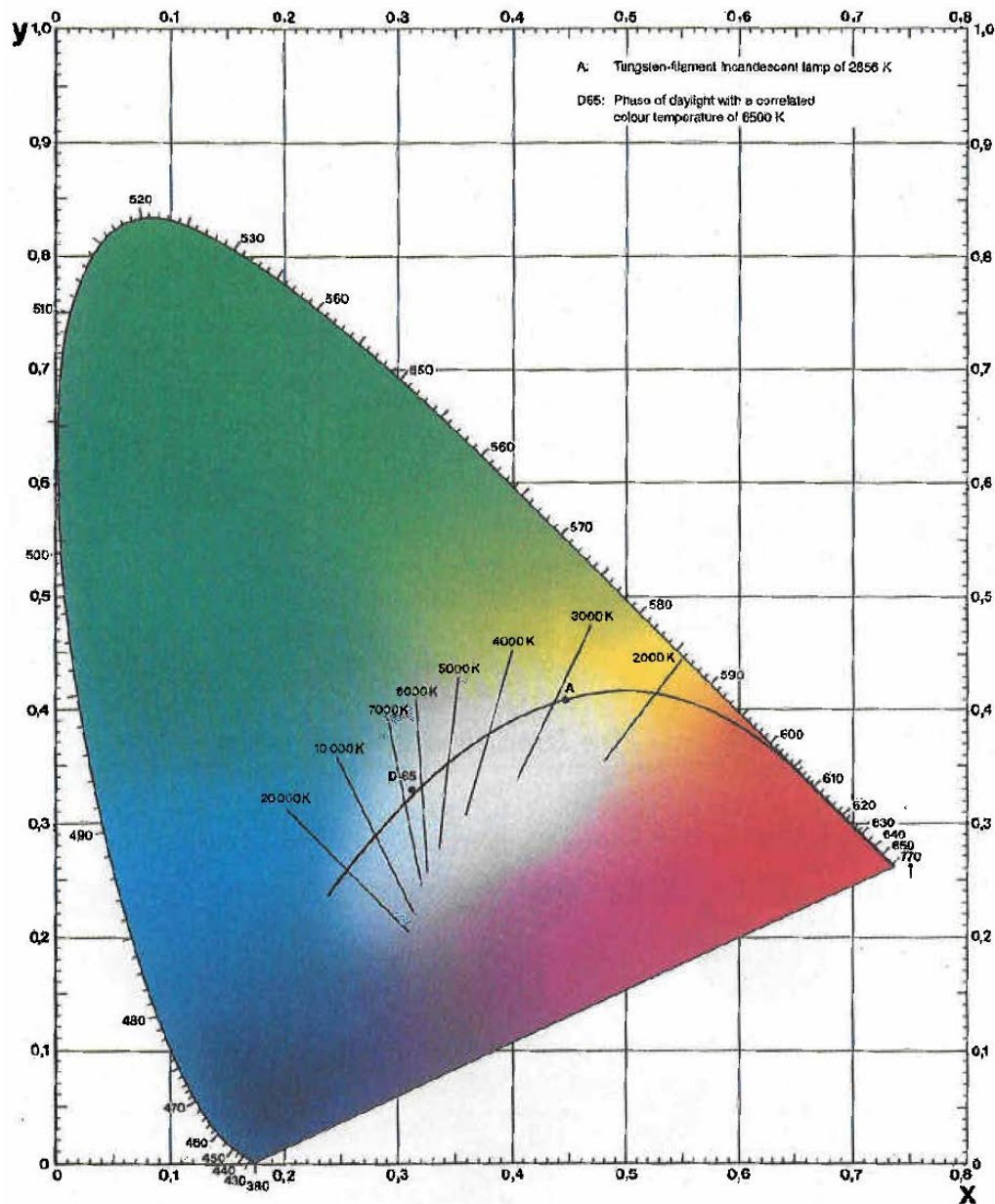


Figure 5B.2.2 The C.I.E. 1931 Chromaticity Diagram

The curved line in the center of Figure 5B.2.2 is known as the *black-body locus* and represents the perceived light color emitted by a *black body* heated to the indicated temperature (in kelvin). In the field of physics, a black body is a theoretical object that is considered to be an ideal emitter of electromagnetic radiation. It absorbs all electromagnetic radiation falling onto it (and thus reflects no radiation), and wavelengths of the radiation emitted by the body are related only to its temperature. Black bodies are so named because at room temperature they would emit mostly infrared radiation, which has a lower frequency and longer wavelength than visible light. Because they would also reflect no radiation, they would appear black. As the temperature of a black body increases, its emitted radiation increases in frequency while shortening in wavelength and begins to be perceived as visible light. Any object hot enough to emit visible light is said to

incandescence, and the phenomenon of visible-light emission due to high temperature is known as *incandescence*.

A lamp's correlated color temperature (CCT) is another commonly computed color property and is based on the behavior of black bodies. The CCT of a lamp is the temperature of a black body that produces roughly the same SPD of light (and thus roughly the same perceived color). Incandescent lamps produce light when electric current is sent through the filament inside the lamp, causing the filament to heat up and incandesce. The SPD generated by incandescent lamps is similar to the SPD generated by a black body; thus, the temperature of the heated filament is near the CCT of the lamp. Many IRLs have a CCT between 2,700 K and 3,000 K.

The color rendering index (CRI) of a lamp is also commonly computed and refers to how closely the perceived color of an object illuminated by that lamp matches the perceived color of the same object illuminated by daylight or black-body radiation. The CRI ranges from 0 to 100; lamps with high CRIs illuminate objects such that humans perceive colors similar to what they would perceive if those objects were illuminated by daylight, or by a black body radiator. Most incandescent lamps without modified spectrums have a CRI near 100.

5B.2.2 Methods of Modifying Spectral Power Distributions

The SPDs that can be generated by incandescence are such that incandescing objects can only produce a narrow subset of all of the colors that the human eye can perceive. To produce colors that are distant from the black-body locus, the SPD of an incandescent object's radiation must be modified in some way. Various methods are used to modify the SPD of IRLs. Some methods utilize specific chemicals, such as neodymium, that are introduced into the cover glass of the lamp. Other methods rely on layers of material that are sandwiched into the cover glass or coatings that are applied to the outside or inside faces of the glass. The compounds, layers, or coatings used to modify the SPD operate by reducing the power of specific wavelengths of light; thus, they act as selective filters. Because the total light output of the IRL is reduced when selective filtering is applied, IRLs with modified spectrums are less efficacious than standard spectrum IRLs of the same filament type, bulb shape, rated voltage, and rated wattage.

5B.3 APPLICATION OF “MODIFIED SPECTRUM” DEFINITION TO IRLS

The definition of “modified spectrum” as specified in the CFR is as follows:
“*Modified spectrum* means, with respect to an incandescent lamp, an incandescent lamp that—

- (1) Is not a colored incandescent lamp; and
- (2) When operated at the rated voltage and wattage of the incandescent lamp—
 - (A) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies below the black-body locus; and
 - (B) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; see § 430.3) that lies at least 4 MacAdam steps, as referenced in IESNA LM-16, distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.”

10 CFR 430.2

The following sections will address each component of this definition in turn as it relates to modified spectrum IRLs.

5B.3.1 Color Requirements

As noted in the definition of “modified spectrum” a modified spectrum lamp cannot be a “colored incandescent lamp.” The statutory definition of “colored incandescent lamp” is as follows:

“*Colored incandescent lamp* means an incandescent lamp designated and marketed as a colored lamp that has—

- (1) A color rendering index of less than 50, as determined according to the test method given in C.I.E. 13.3 (incorporated by reference; see § 430.3); or
- (ii) A correlated color temperature of less than 2,500K, or greater than 4,600K, where correlated temperature is computed according to the “Computation of Correlated Color Temperature and Distribution Temperature,” Journal of the Optical Society of America, (incorporated by reference; see § 430.3).”

10 CFR 430.2

Most IRLs with unmodified spectrums have a CRI near 100 and a CCT between 2,700 K and 3,000 K, and therefore would not be considered colored incandescent lamps. Colored incandescent lamps are lamps that have been modified, using coatings or other methods, so that they produce light that is perceived as blue, red, green, or other colors. These lamps are used for aesthetic or artistic effects and thus are not meant to reproduce object colors accurately. Although colored incandescent lamps are modified, they are excluded from the definition of modified spectrum.

5B.3.2 Black-Body Locus Requirements

The “modified spectrum” definition also requires that a modified spectrum incandescent lamp produce a perceived color with a “color point ... that lies below the black-body locus” on the C.I.E. 1931 chromaticity diagram when the lamp is operated at its rated voltage and wattage. 10 CFR 430.2 The chromaticity diagram and black-body locus are shown in Figure 5B.3.1, along with red straight lines indicating color requirements. The combined color and black-body locus requirements of the “modified spectrum” definition exclude all lamps with color points outside of the dark grey area in the figure.

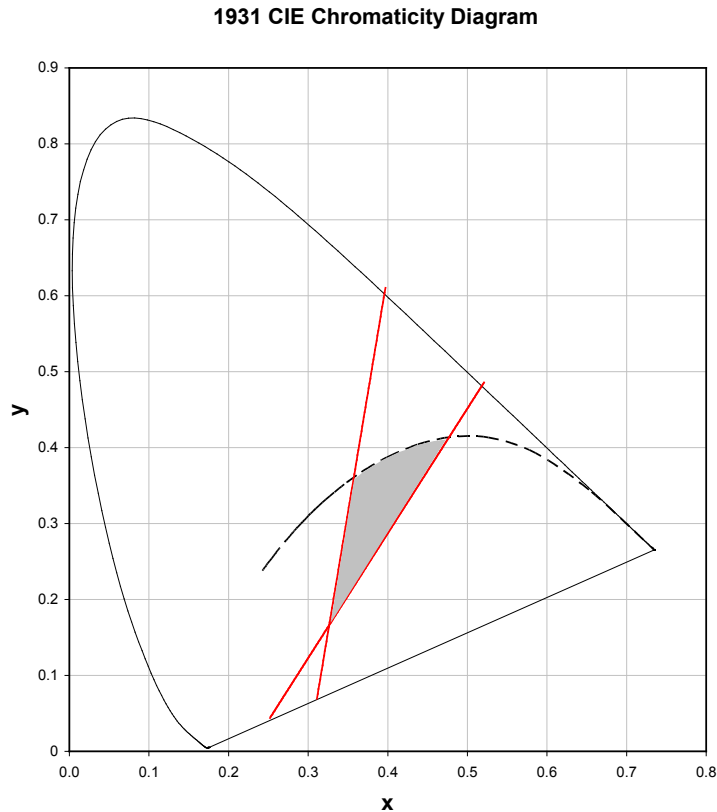


Figure 5B.3.1 Combined Black-Body Locus and Color Requirements of the “Modified Spectrum” Definition

5B.3.3 MacAdam-Step Requirements

Finally, the “modified spectrum” definition requires that a modified spectrum incandescent lamp have a color point that “lies at least 4 MacAdam steps ... distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.” 10 CFR 430.2 Requiring the color point to be “at least 4 MacAdam steps ... distant from the color point of a clear lamp” ensures that modified spectrum lamps will be noticeably different in color than similar clear lamps.

Figure 5B.3.2 shows a magnification of the C.I.E. 1931 chromaticity diagram with an example of three IRL samples that meet the definition of “modified spectrum.” The color points of the three standard spectrum and three modified spectrum IRL samples in this pair are shown as blue dots in the figure. The modified spectrum IRLs have color points located below the black-body locus, shown by the black line. In addition, they meet the color requirements bounded by the red straight line at the right (the left bound is located outside of the area shown by the figure). Finally, their color points meet the MacAdam-step requirement established by the three corresponding standard spectrum lamps located in the center of the red ellipse; the red ellipse represents a distance of four MacAdam steps from the average color point of the standard spectrum IRLs.

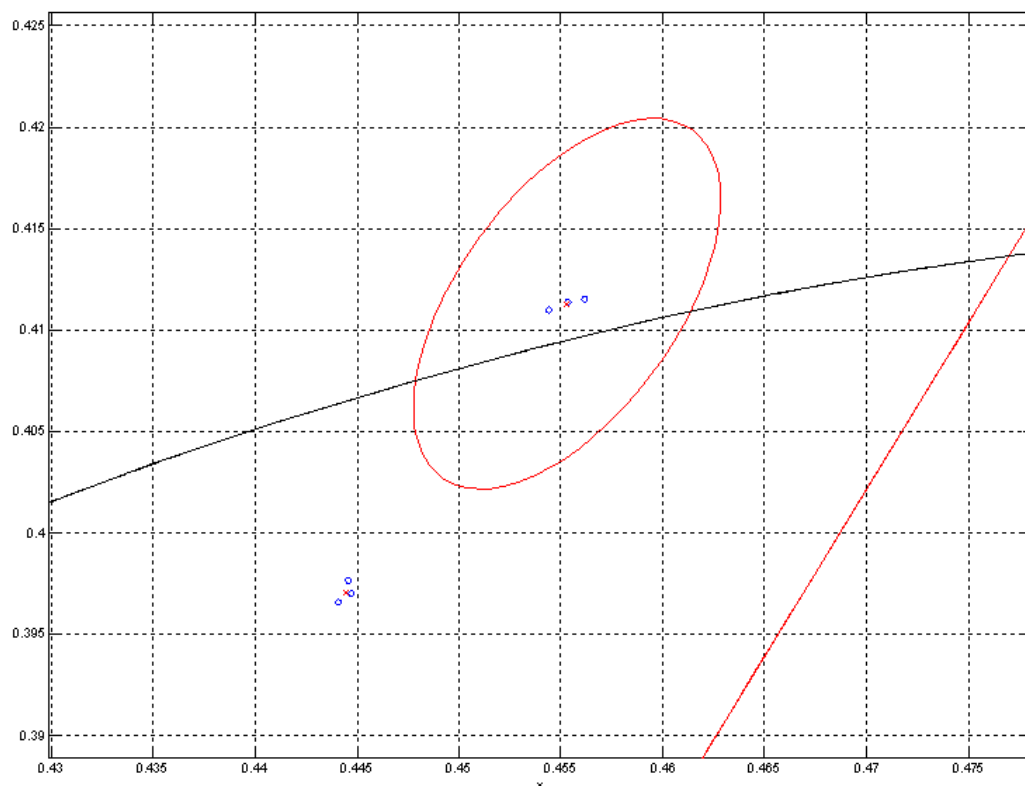


Figure 5B.3.2 Example of IRLs That Meet the Definition of “Modified Spectrum;” Modified Spectrum IRLs Color Points Lie to the Lower Left of the Red Circle

Applying the definition of “modified spectrum” requires comparing the color point of the IRL in question to the color point of a clear lamp. IRLs, however, are not clear lamps because they have reflectors; IRLs also commonly have frosted or textured faces. In order to apply the definition of “modified spectrum,” DOE developed a normalization method to model a clear lamp in the 2009 Lamps Rule. This method is discussed as part of section 5B.4.

5B.4 METHODOLOGY FOR STANDARD AND MODIFIED SPECTRUM COMPARISON

To explore the efficacy differences between standard spectrum and modified spectrum IRLs, DOE paired commercially available standard spectrum IRLs with available IRLs in the same product line that were marketed as featuring spectral modification (for example, IRLs marketed as “daylight” or “full-spectrum” lamps) in manufacturers’ catalogs or marketing literature. Standard spectrum lamp models were paired with the lamps featuring spectral modification such that the lamps in each pair had the same bulb shape, the same rated life, the same rated voltage and wattage, and the same class of filament shape. All lamps had a rated voltage of 120 volts.

In total, DOE tested seven pairs of parabolic aluminized reflector (PAR) lamps from two major manufacturers. Six pairs consisted of halogen lamps, and one pair consisted of halogen infrared (HIR) lamps. Each pair contained three samples of an IRL model marketed as featuring

spectral modification along with three samples of a corresponding standard spectrum IRL model in the same product line. Halogen and HIR lamps were selected because these design options are required to meet the standards adopted by the 2009 Lamps Rule. DOE also tested one lamp pair featuring a smaller diameter (PAR16) than IRLs covered by this rulemaking, in order to supplement its analysis of larger-diameter lamps.

DOE measured and recorded the SPDs of the standard spectrum IRL samples in each pair, in accordance with DOE test procedures as specified in 10 CFR Appendix R to Subpart B of Part 430. Using the same guidelines, DOE also measured and recorded the SPDs of the samples of lamps marketed as featuring spectral modification. DOE then utilized the SPDs to compute the MacAdam-step shift and corresponding lumen output reductions between the standard spectrum and spectrally modified lamps across the lamp samples in every lamp pair.

Because the MacAdam-step shift specified in DOE's definition of modified spectrum lamp is relative to a clear lamp, DOE had to account for the fact that standard spectrum IRLs are not clear lamps due to the impact of their cover glass and their reflectors. DOE thus developed a methodology to isolate the effects of spectrum modification in order to determine the relative reduction in lumen output and the relative change in color that would be observed if a spectrally modified IRL were compared to a clear lamp. The method also assumes that spectrum modification is achieved through the usage of neodymium in the cover glass of a modified spectrum lamp. DOE used a model that simulates the SPD of a halogen capsule without any cover glass, termed H_{SPD} in the equation below. This SPD is then used to simulate a clear lamp. The methodology utilizes the equation shown below in Eq. 5B.1:

$$H_{SPD} * \tau_N^\beta * \tau_{CG} = M_{SPD} \rightarrow \left(\alpha * SA * \frac{c_1 * 10^{-9}}{\lambda^5 \left(e^{\frac{c_2}{T\lambda}} - 1 \right)} \right)_{\lambda=380}^{780} * \varepsilon_W * \tau_N^\beta * \tau_{CG} = M_{SPD} \quad \text{Eq. 5B.1}$$

Where:

$$c_1 = 2\pi h c^2 \quad \text{W} \cdot \text{m}^2$$

$$c_2 = \frac{hc}{k} \quad \text{m} \cdot \text{K}$$

$$c = 2.99792458 \times 10^8 \quad \text{m/s (velocity of light)}$$

$$h = 6.626176 \times 10^{-34} \quad \text{J} \cdot \text{s (Planck constant)}$$

$$k = 1.380662 \times 10^{-23} \quad \text{J/K (Boltzmann constant)}$$

and:

H_{SPD} : the simulated spectral power distribution of a halogen or HIR capsule

M_{SPD} : the measured spectral power distribution of a spectrally modified lamp

λ : wavelength of light emitted from the lamp filament (in meters)

T: temperature of the filament (in kelvin)

SA: surface area of the filament (in square meters), determined by selecting a black-body radiator with the same radiant power as the measured standard spectrum IRL
 α : correction term for the filament surface area
 ϵ_W : emissivity of tungsten, which models a tungsten filament
 τ_N : transmittance of neodymium in a spectrally modified cover glass
 τ_{CG} : transmittance of a clear cover glass
 β : combined effect of neodymium concentration and thickness of neodymium in a spectrally modified cover glass

Transmittance is the fraction of light (at a specific wavelength) hitting an object that travels through the object and can be measured on the other side. To determine the transmittance, DOE measured the transmittance of a standard spectrum cover glass, τ_{CG} , between the wavelengths of 380 nm and 780 nm. DOE also measured τ_N using a spectrally modified lamp cover glass. The cover glass transmittance for a specific lamp featuring spectral modification tested by DOE is shown relative to the corresponding standard spectrum lamp transmittance in Figure 5B.4.1. Sharp dips in the plot clearly indicate which light wavelengths are absorbed by the combination of neodymium and cover glass.

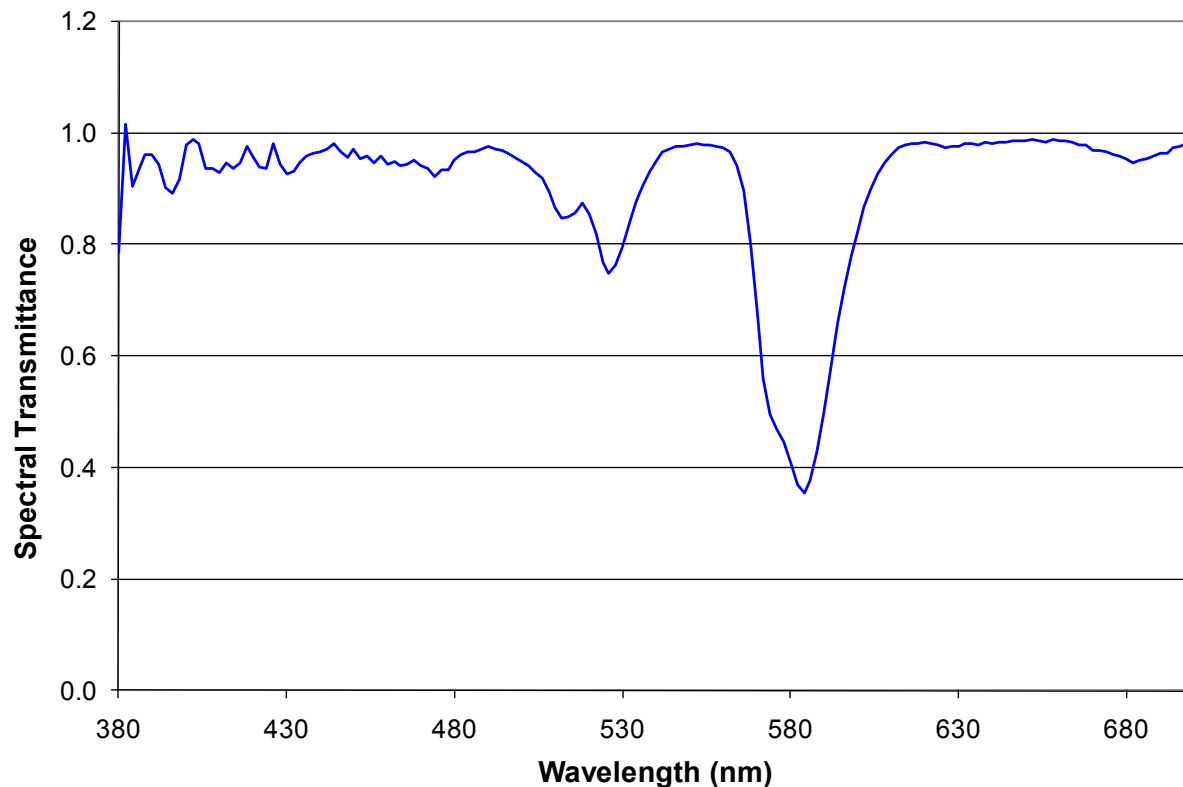


Figure 5B.4.1 Transmittance of a Specific Lamp Cover Glass Featuring Neodymium, Relative to the Standard Spectrum Cover Glass Transmittance

DOE utilized an unconstrained nonlinear optimization program to compute α , β , and T and thus model the SPD of the capsule inside of a spectrally modified lamp, H_{SPD} . DOE then used H_{SPD} and the transmittance of a cover glass without any spectrum-modifying features in Eq. 5B.2 in order to obtain I_{SPD} , the SPD of a clear lamp:

$$H_{SPD} * \tau_{CG} = I_{SPD} \quad \text{Eq. 5B.2}$$

The light output reduction is obtained by dividing M_{SPD} by I_{SPD} . In addition, both I_{SPD} and M_{SPD} were used to calculate color points. Then, the color separation from the I_{SPD} color point to the M_{SPD} color point was determined in terms of MacAdam steps.

DOE determined the relationship between MacAdam-step shift and light output reduction, as shown in Table 5B.4.1 and Figure 5B.4.2, for every individual lamp combination tested (21 combinations of standard spectrum and spectrally modified lamps, derived from the seven lamp pairs that each contained three standard spectrum and three spectrally modified lamp samples).

Table 5B.4.1 MacAdam-Step Shifts and Light Output Reductions for Lamps Tested

Lamp ID		alpha	beta	T	MacAdam-Step Shift	Light Output Reduction
Standard Spectrum	Spectrally Modified					
105352	105349	1.249	1.076	2,746.221	5.4	19.2%
105353	105350	1.239	1.146	2,746.022	5.7	20.1%
105354	105351	1.290	1.116	2,741.640	5.6	19.7%
105374	105371	1.323	1.086	2,715.983	5.5	19.3%
105375	105372	1.344	1.096	2,707.611	5.5	19.5%
105376	105373	1.273	1.029	2,726.019	5.2	18.6%
106705	106702	1.275	0.981	2,845.517	5.0	17.9%
106706	106703	1.296	1.066	2,838.923	5.4	19.0%
106707	106704	1.271	1.055	2,857.426	5.4	18.9%
106751	106748	1.498	0.473	2,699.566	2.4	10.0%
106752	106749	1.488	0.374	2,678.070	1.8	8.2%
106753	106750	1.803	0.395	2,653.760	1.9	8.6%
105355	105276	1.337	0.425	2,739.313	2.1	9.1%
105356	105277	1.411	0.500	2,750.256	2.5	10.5%
105357	105278	1.305	0.430	2,751.663	2.1	9.2%
105358	105269	1.315	0.456	2,818.707	2.3	9.7%
105359	105270	1.272	0.448	2,818.681	2.3	9.5%
105360	105271	1.256	0.473	2,821.212	2.4	10.0%
105363	105287	1.208	0.547	2,760.137	2.8	11.3%
105364	105288	1.337	0.541	2,784.910	2.7	11.2%
105377	105289	1.325	0.495	2,770.849	2.5	10.4%

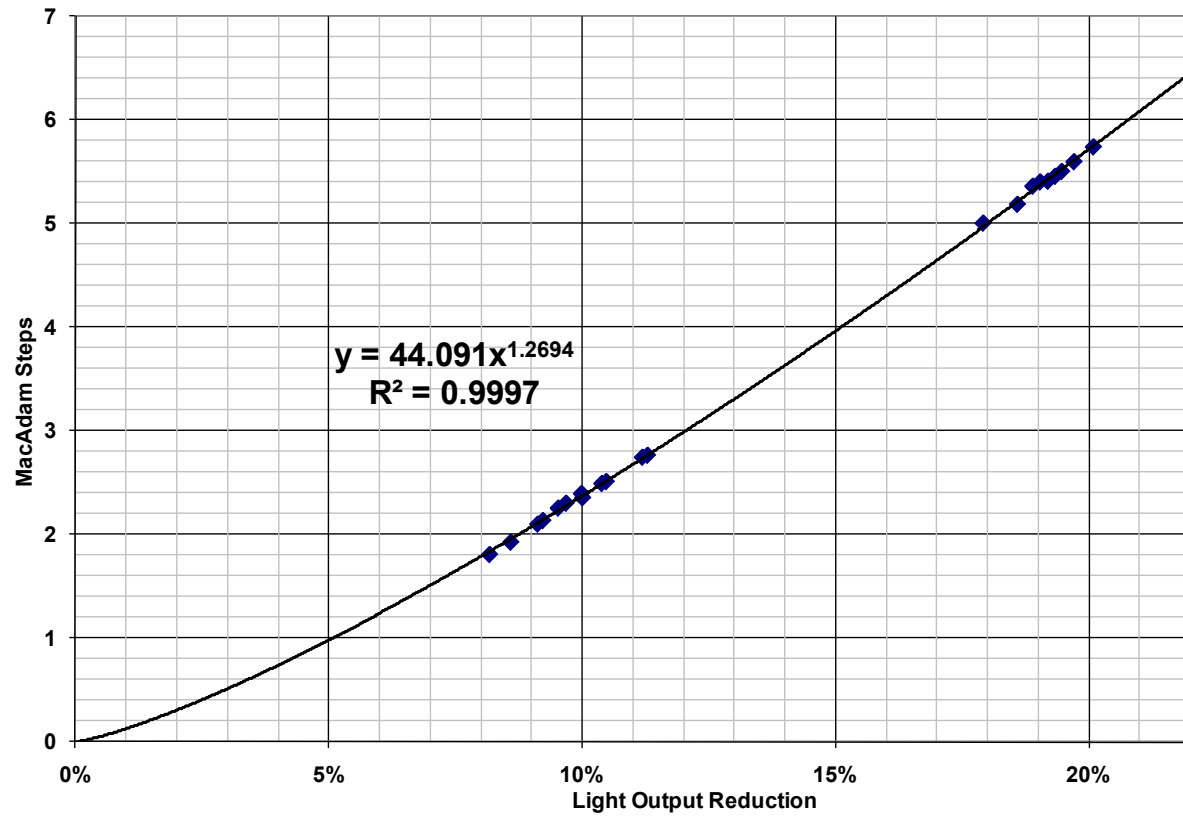


Figure 5B.4.2 Relationship Between Light Output Reduction and MacAdam-Step Shift For Lamps Tested

5B.5 SELECTION OF SCALING FACTOR

The results of DOE's analysis of commercially available lamps for the 2009 Lamps Rule indicated that a 4-MacAdam-step shift between a standard spectrum IRL and a lamp featuring spectral modifications corresponded with an approximate efficacy reduction of 15 percent, which was the scaling factor used in the 2009 Lamps Rule. For this rulemaking, DOE is maintaining 15 percent as the efficacy reduction factor required of IRLs that meet the "modified spectrum" definition. A comparison of the baseline and EL put forth in this rulemaking for standard spectrum and modified spectrum IRLs with this scaling factor applied is shown in Figure 5B.5.1.

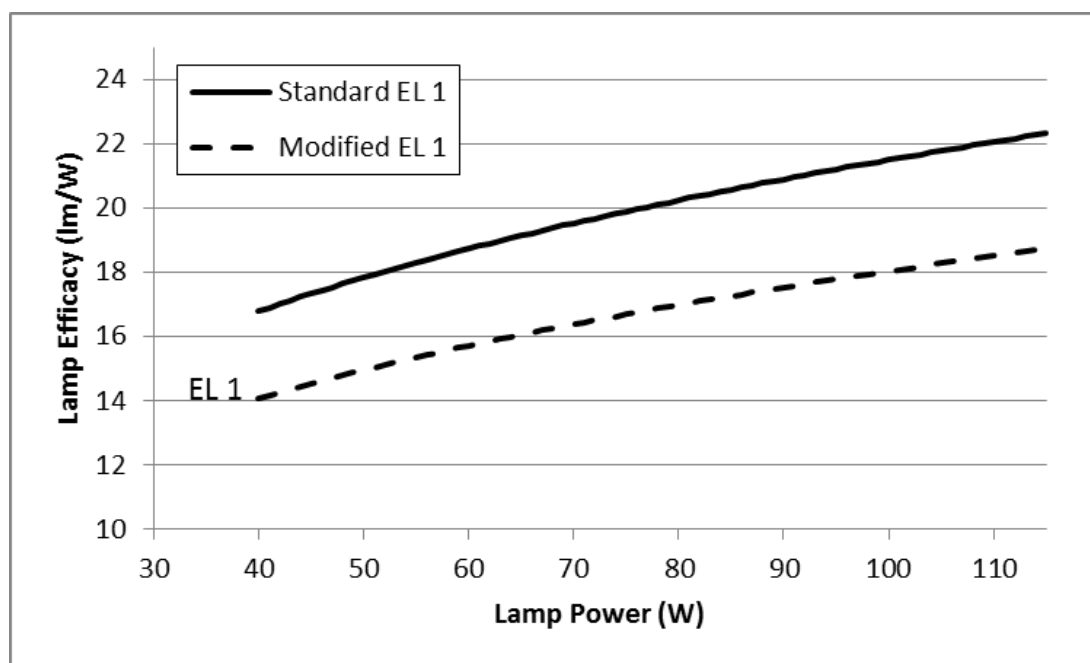


Figure 5B.5.1 Comparison of Standard Spectrum and Modified Spectrum for EL 1

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² International Energy Agency. *Light's Labour's Lost: Policies for Energy-efficient Lighting*. OECD/IEA, 2006.

³ D. L. MacAdam, "Visual Sensitivities to Color Differences in Daylight," J. Opt. Soc. Am. 32, 247-273 (1942).

APPENDIX 6A. LIGHTING CONTROLS

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APPENDIX 6A. LIGHTING CONTROLS

6A.1 INTRODUCTION

The U.S. Department of Energy (DOE) evaluated the effects of lighting controls on the energy consumption of general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs). Most lighting controls have one of two impacts: reducing operating wattage or reducing operating hours. DOE refers to these two groups of controls as dimmers/light sensors and occupancy sensors, respectively. The operating hours reported in the 2010 U.S. Lighting Market Characterization (LMC), which are used to determine the national average operating hours for the energy use characterization of this notice of proposed rulemaking (NOPR) (see chapter 6 of this NOPR technical support document [TSD]), already account for occupancy sensors as they are based on building surveys and metering data. Therefore, no additional analysis was conducted to determine the effects of occupancy sensors.

Dimmers reduce the power of lamps, thereby reducing their energy consumption and resulting in lower operating costs. This chapter evaluates the impact of dimmers on the annual energy consumption for GSFLs and IRLs. DOE used these annual energy consumption results to conduct sensitivities for the life-cycle cost (LCC) and payback period (PBP) analysis. See appendix 8B of this TSD for the LCC savings of GSFLs and IRLs operated on dimming systems.

6A.2 GENERAL SERVICE FLUORESCENT LAMPS

DOE assessed the impacts of dimmers on GSFLs by determining the reduction in system lumen output and system input power as a result of using dimming ballasts. Based on product research and manufacturer feedback, DOE determined that lamps in the 4-foot medium bipin (MBP), 4-foot T5 miniature bipin (MiniBP) standard output (SO), and 4-foot T5 MiniBP high output (HO) product classes are most commonly paired with dimming ballasts. Additionally, DOE determined that fluorescent dimming is most commonly used in the commercial and industrial sectors and is not frequently employed in the residential sector. DOE decided to analyze dimming scenarios for 2-lamp 4-foot MBP systems, 4-lamp 4-foot MBP systems, 2-lamp 4-foot T5 MiniBP SO systems, and 2-lamp 4-foot T5 MiniBP HO systems operating in the commercial and industrial sectors.

DOE identified the most common dimming ballasts on the market and paired them with the representative lamps identified in the engineering analysis. DOE developed a database of commercially available dimming ballasts to determine the most common characteristics of products designed to operate 4-foot MBP, 4-foot T5 MiniBP SO, and 4-foot T5 MiniBP HO lamps. DOE found that there are two types of dimming ballasts: step dimming and continuous dimming. Step dimming ballasts restrict dimming to fixed percentages of light output, while continuous dimming ballasts allow for dimming across a full range of light output levels. DOE also found that, similar to fixed light output ballasts, multiple starting methods are available for dimming ballasts, including instant start and programmed start (PS). DOE concluded through manufacturer feedback and a review of product offerings that continuous dimming, PS ballasts were the most common dimming ballasts across all lamp types analyzed. DOE examined all

ballasts of this type and selected models with the most common performance characteristics (*i.e.*, ballast factor [BF] and ballast luminous efficiency [BLE]) in order to best represent the typical ballasts available on the market.

DOE next considered if dimming ballasts operate both full wattage and reduced wattage lamps in practice. Based on manufacturer feedback and product literature, DOE concluded that full wattage lamps are more frequently paired with dimming ballasts. Further, some manufacturers do not advise using reduced wattage lamps with dimming ballasts and thus do not cover such a system under warranty. However, DOE found that the acceptance of reduced wattage lamps in dimming applications varied by manufacturer and lamp type. DOE determined that a substantial number of dimming ballasts are compatible with reduced wattage 4-foot MBP lamps and thus concluded that reduced wattage lamps should be included in the dimming analysis for the 4-foot MBP product class. DOE found significantly fewer dimming ballasts advertised as compatible with reduced wattage 4-foot T5 MiniBP HO and 4-foot T5 MiniBP SO lamps, and therefore decided not to analyze reduced wattage replacements in the dimming scenario for these lamp types.

Once DOE selected the appropriate dimming ballasts, DOE calculated the system input power for the ballasts when paired with the representative lamps from the engineering analysis. Through manufacturer feedback and research,¹ DOE concluded that the average reduction of system lumen output for GSFLs was 33 percent. The BF of the baseline lamp-and-ballast system was then calculated using the catalog BF at 100 percent light output and adjusting the value to reflect that the system would be dimmed by 33 percent (*i.e.*, 67 percent of full light output). Next, the system mean lumen output was calculated using the baseline lamp's catalog mean lumen output, the number of lamps in the lamp-and-ballast system, and, finally, the BF associated with 67 percent of full light output. DOE assumed that each higher efficacy lamp-and-ballast system would be dimmed to the mean lumen output of the baseline system. Thus, for each representative unit at a higher efficacy level (EL), the BF was calculated given the specific lamp's mean lumen output, number of lamps in the system, and total mean lumen output of the system (assumed to be equal to that of the baseline system). DOE calculated the percentage each higher efficacy lamp-and-ballast system was dimmed by dividing the calculated BF by the catalog BF at full light output.

For dimming ballasts, manufacturers' catalogs report performance characteristics for ballasts operating lamps at both the maximum and minimum possible light outputs. To calculate system input power as a result of dimming, DOE plotted the maximum and minimum light output levels and associated system input powers for the lamp types analyzed. A linear equation was fit to the points and used to derive the system input power for the calculated light output at each EL. For 4-foot MBP lamps, separate linear equations were developed for each reduced wattage system.

DOE also calculated the BLE for each dimming ballast using the calculated system input power, or ballast input power, and total lamp arc power. DOE calculated total lamp arc power by multiplying the high-frequency reference lamp arc power, the BF, and the number of lamps; see chapter 5 of this TSD for more information. DOE computed the BLE at the given percentage of light output using Eq. 6A.1.

$$BLE = \frac{Total\ Lamp\ Arc\ Power}{Ballast\ Input\ Power} * 100 * \beta$$

Eq. 6A.1

Where:

$\beta = 1.0$ for high-frequency ballasts

The following tables present the system performance characteristics at the baseline and each EL for the dimming scenario. Note the lamp lifetimes in the dimming lamp-and-ballast systems are consistent with the rated lifetime of the lamp when paired with a PS ballast because fluorescent lamp lifetime is not typically affected by dimming. Additionally, unlike the engineering analysis, separate scenarios for lamp replacement and lamp-and-ballast replacement are not presented for the dimming analysis because energy savings can be achieved for all higher efficacy lamp-and-ballast combinations; that is, lamps with more light output are dimmed by a larger percentage to match the light output of the baseline system and therefore consume less energy.

Table 6A.2.1 presents the dimming analysis results for the 2-lamp 4-foot MBP product class in the commercial and industrial sectors. As discussed earlier, the ballast factor is adjusted so as to normalize the system mean lumen output across ELs.

Table 6A.2.1 Dimming Analysis for a Two-Lamp 4-foot MBP System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Starting Method	Ballast Factor	Percent of Light Output	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		<i>W</i>	<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>lm</i>	<i>hr</i>				<i>W</i>		<i>lm</i>	<i>lm</i>
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	PS	0.59	67%	42.1	81.3	3,420	3,213
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	PS	0.58	66%	41.6	80.9	3,393	3,213
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	PS	0.68	78%	36.7	90.1	3,384	3,213
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	PS	0.55	62%	39.8	79.5	3,382	3,213
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	PS	0.62	70%	37.8	85.3	3,381	3,213

Table 6A.2.2 presents the dimming analysis results for the 4-lamp 4-foot MBP product class in the commercial and industrial sectors. As discussed earlier, the ballast factor is adjusted so as to normalize the system mean lumen output across ELs.

Table 6A.2.2 Dimming Analysis for a Four-Lamp 4-foot MBP System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy	Initial Lamp Light Output	Mean Lamp Light Output	Rated Life	Starting Method	Ballast Factor	Percent of Light Output	System Input Power	BLE	System Initial Light Output	System Mean Light Output
		<i>W</i>	<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>lm</i>	<i>hr</i>				<i>W</i>		<i>lm</i>	<i>lm</i>
Baseline	T8	32	32.5	89.2	2,900	2,725	40,000	PS	0.59	67%	81.2	84.3	6,839	6,427
EL 1	T8	32	32.5	90.0	2,925	2,770	30,000	PS	0.58	66%	80.2	83.9	6,786	6,427
EL 2	T8	25	26.6	93.0	2,475	2,350	40,000	PS	0.68	78%	73.7	89.8	6,768	6,427
EL 2	T8	32	32.5	95.4	3,100	2,945	40,000	PS	0.55	62%	76.8	82.4	6,765	6,427
EL 2	T8	28	28.4	96.0	2,725	2,590	40,000	PS	0.62	70%	73.3	88.1	6,762	6,427

Table 6A.2.3 presents the dimming analysis results for the 2-lamp 4-foot T5 MiniBP SO product class in the commercial and industrial sectors. As discussed earlier, the ballast factor is adjusted so as to normalize the system mean lumen output across ELs.

Table 6A.2.3 Dimming Analysis for a Two-Lamp 4-foot T5 MiniBP SO System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Starting Method	Ballast Factor	Percent of Light Output	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		<i>W</i>	<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>lm</i>	<i>hr</i>				<i>W</i>		<i>lm</i>	<i>lm</i>
Baseline	T5	28	27.8	94.6	2,630	2,446	30,000	PS	0.67	67%	44.7	83.4	3,524	3,277
EL 1	T5	28	27.8	104.3	2,900	2,697	30,000	PS	0.61	61%	41.4	81.6	3,524	3,277
EL 2	T5	28	27.8	109.7	3,050	2,898	30,000	PS	0.57	57%	39.2	80.3	3,449	3,277

Table 6A.2.4 presents the dimming analysis results for the 2-lamp 4-foot T5 MiniBP HO product class in the commercial and industrial sectors. As discussed earlier, the ballast factor is adjusted so as to normalize the system mean lumen output across ELs.

Table 6A.2.4 Dimming Analysis for a Two-Lamp 4-foot T5 MiniBP HO System in the Commercial and Industrial Sectors

Efficacy Level	Lamp Diameter	Nominal Wattage	Rated Wattage	Rated Efficacy at 35 °C	Initial Lamp Light Output at 35 °C	Mean Lamp Light Output at 35 °C	Rated Life	Starting Method	Ballast Factor	Percent of Light Output	System Input Power	BLE	System Initial Light Output at 35 °C	System Mean Light Output at 35 °C
		<i>W</i>	<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>lm</i>	<i>hr</i>				<i>W</i>		<i>lm</i>	<i>lm</i>
Baseline	T5	54	53.8	83.6	4,498	4,273	25,000	PS	0.67	67%	84.0	85.8	6,027	5,726
EL 1	T5	54	53.8	92.9	5,000	4,750	25,000	PS	0.60	60%	77.3	83.9	6,027	5,726

6A.3 INCANDESCENT REFLECTOR LAMPS

For IRLs, DOE evaluated two dimming scenarios. In one scenario (hereafter “All Dimmers”), DOE considered the performance characteristics of individual lamps when operated on dimmers. In another scenario (hereafter “Distribution of Dimmers”), DOE considered characteristics of dimming that were representative of national behavior; that is, DOE used the percent of consumers that use dimmers to calculate weighted-average results.

Based on research, DOE determined that on average, consumers using dimmers reduce wattage by 20 percent, corresponding to a lumen reduction of 25 percent.^{2 3} Therefore, for the All Dimmers scenario, the reduction in energy use was 20 percent for lamps at the baseline.

As discussed in chapter 3 of this TSD, dimmed lamps often have increased lifetimes compared to lamps that operate at full light output. Given the reduction in power and lumen output described above, DOE calculated the increased lifetime of dimmed lamps in this analysis. To make these adjustments, DOE identified a relationship between the amount of dimming (*i.e.*, reduction in lumens) and the change in power rating and lifetime,⁴ outlined in Table 6A.3.1. For example, for a 25 percent lumen reduction in the All Dimmers scenario, the wattage was reduced by 20 percent and the lifetime was multiplied by 3.94.

Table 6A.3.1 Adjustments to LCC Inputs Based on Dimmer Usage

Reduction in Lumens %	Power Rating Wattage Reduction %	Lifetime Multiplier*
0	0	1.00
2.5	2	1.23
5	4	1.46
10	10	2.04
15	15	2.48
20	18	3.21
25	20	3.94
30	24	5.55
35	28	7.45
40	32	10.95
45	36	13.87
50	40	14.60
* Calculated from source data by comparing the change in reference lamp lifetime from a 0 percent reduction to the selected reduction in lumens. DOE applied this multiplier to its lamp lifetime estimates. The maximum multiplier is 14.60 at a 50 percent reduction in lumens. After this point, all further reductions in lumens receive a constant lifetime multiplier of 14.60.		

In the All Dimmers scenario and Distribution of Dimmers scenario, DOE assumed that consumers who have higher efficacy lamps with higher lumen output would use their dimmer to equalize lumen output with that of the baseline lamp. Once DOE determined the necessary reduction in lumen output, DOE identified the corresponding reduction in power rating and increase in lamp lifetime using Table 6A.3.1.

Additionally, for the Distribution of Dimmers scenario, DOE also evaluated an alternative assumption that consumers who have higher efficacy lamps with dimmers do not maintain the lumen output of the baseline lamp but instead reduce the lumen output of the higher efficacy lamp by the same percentage lumen reduction that occurs for lamps at the baseline.

As discussed in chapter 5 of this NOPR TSD, DOE evaluated two representative lamp units at EL 1 for IRLs, a 2,500-hour halogen-infrared (HIR) lamp and a 4,200-hour improved HIR lamp. Table 6A.3.2 and Table 6A.3.3 present the performance characteristics for these lamps due to dimming in the All Dimmers scenario in the commercial and residential sectors.

Table 6A.3.2 Dimming Analysis for a 55 W PAR38 2,500 Hour HIR EL 1 Representative Lamp in the Commercial or Residential Sectors, All Dimmers Scenario

Efficacy Level	Lamp Descriptor	Wattage	Efficacy	Initial Lamp Light Output	Life
		<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>hr</i>
Baseline	PAR38 Improved Halogen	48.0	16.7	803	5,913
EL 1	PAR38 HIR	46.8	17.2	803	6,205

Table 6A.3.3 Dimming Analysis for a 55 W PAR38 4,200 Hour Improved HIR EL 1 Representative Lamp in the Commercial or Residential Sectors, All Dimmers Scenario

Efficacy Level	Lamp Descriptor	Wattage	Efficacy	Initial Lamp Light Output	Life
		<i>W</i>	<i>lm/W</i>	<i>lm</i>	<i>hr</i>
Baseline	PAR38 Improved Halogen	48.0	16.7	803	5,913
EL 1	PAR38 Improved HIR	44.0	18.2	803	16,556

For the Distribution of Dimmers scenario, using the performance characteristics for dimming developed for the All Dimmers scenario, DOE determined the LCC savings and PBP for lamps utilizing dimmers. DOE then calculated the weighted average LCC savings and PBP for lamps operating on dimmers and those that are not using the estimated distribution of dimmers. Based on data from the 2010 LMC, DOE estimated that 29 percent of halogen IRLs operate on dimmers or light sensors in the residential sector and 5 percent of halogen IRLs operate on dimmers in the commercial sector.⁵

6A.4 RESULTS OF THE ENERGY USE CHARACTERIZATION FOR LIGHTING CONTROLS

DOE calculated the annual energy consumption using the power rating estimates determined for dimming scenarios analyzed (see section 6A.2 for GSFLs and section 6A.3 for

IRLs) and the annual operating hours. The annual energy use estimates for GSFLs and IRLs in these dimming scenarios are presented in the sections below.

6A.4.1 General Service Fluorescent Lamps

Using annual operating hours and system input power, DOE calculated the annual energy consumption of the dimmed lamp-and-ballast system. The following tables detail (1) the system input power for all GSFLs operated on dimming systems; and (2) average annual energy consumption using the U.S. weighted average of annual operating hours in each sector. The average GSFL annual operating hours for the U.S. residential, commercial, and industrial sectors are 634 hours, 4,065 hours, and 4,587 hours, respectively. (For further information on operating hours, see chapter 6 of this NOPR TSD.)

Table 6A.4.1 Annual Energy Consumption for the Dimmed 4-Foot Medium Bipin T8 GSFL 2-Lamp Programmed Start System, Commercial and Industrial Sectors

EL	Technology Option	System Input Power	Annual Energy Consumption	
			Commercial	Industrial
		<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	0.59BF32.5 Elec	42.1	171.0	193.0
EL 1	0.58BF32.5 Elec	41.6	169.0	190.7
EL 2	0.68BF26.6 Elec	36.7	149.3	168.4
EL 2	0.55BF32.5 Elec	39.8	161.8	182.6
EL 2	0.62BF28.4 Elec	37.8	153.7	173.5

Table 6A.4.2 Annual Energy Consumption for the Dimmed 4-Foot Medium Bipin T8 GSFL 4-Lamp System Programmed Start, Commercial and Industrial Sectors

EL	Technology Option	System Input Power	Annual Energy Consumption	
			Commercial	Industrial
		<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	0.59BF32.5 Elec	81.2	329.9	372.3
EL 1	0.58BF32.5 Elec	80.2	326.1	368.0
EL 2	0.68BF26.6 Elec	73.7	299.7	338.2
EL 2	0.55BF32.5 Elec	76.8	312.1	352.3
EL 2	0.62BF28.4 Elec	73.3	297.8	336.0

Table 6A.4.3 Annual Energy Consumption for the Dimmed 4-Foot T5 Miniature Bipin Standard Output GSFL 2-Lamp System, Commercial and Industrial Sectors

EL	Technology Option	System Input Power	Annual Energy Consumption	
			Commercial	Industrial
		<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	0.67BF27.8 Elec	44.7	181.5	204.9
EL 1	0.61BF27.8 Elec	41.4	168.2	189.9
EL 2	0.57BF27.8 Elec	39.2	159.2	179.7

Table 6A.4.4 Annual Energy Consumption for the Dimmed 4-Foot T5 Miniature Bipin High Output GSFL 2-Lamp System, Commercial and Industrial Sectors

EL	Technology Option	System Input Power	Annual Energy Consumption	
			Commercial	Industrial
		<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	0.67BF53.8 Elec	84.0	341.4	385.3
EL 1	0.60BF53.8 Elec	77.3	314.1	354.4

6A.4.2 Incandescent Reflector Lamps

Because an IRL does not require a ballast to operate, the rate of energy usage is simply the power of the dimmed lamp. DOE calculated the annual energy consumption based on the U.S. weighted-average annual operating hours for IRLs in the residential and commercial sectors, which are 763 hours and 4,532 hours, respectively. (For further information on operating hours, see chapter 6 of this NOPR TSD.)

Table 6A.4.5 and Table 6A.4.6 present annual energy consumption in the All Dimmers scenario in the commercial and residential sectors, in which lumens are equalized with the baseline lamp lumens in the commercial and residential sectors.

Table 6A.4.5 Annual Energy Consumption for a 55 W PAR38, 2,500 hour HIR EL 1 Representative Lamp, Commercial or Residential Sectors, All Dimmers Scenario

EL	Lamp Efficacy	Lamp Power Rating	Annual Energy Consumption	
			Commercial	Residential
	<i>lm/W</i>	<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	16.7	48.0	217.5	36.6
EL 1	17.2	46.8	211.9	35.7

Table 6A.4.6 Annual Energy Consumption for a 55 W PAR38, 4,200 hour Improved HIR EL 1 Representative Lamp, Commercial or Residential Sectors, All Dimmers Scenario

EL	Lamp Efficacy	Lamp Power Rating	Annual Energy Consumption	
			Commercial	Residential
	<i>lm/W</i>	<i>W</i>	<i>kWh</i>	<i>kWh</i>
Baseline	16.7	48.0	217.5	36.6
EL 1	18.2	44.0	199.4	33.6

Table 6A.4.7 through Table 6A.4.8 present the weighted average annual energy consumption in the Distribution of Dimmers scenario, in which lumens are equalized with the baseline lamp lumens in the commercial and residential sectors.

Table 6A.4.7 Annual Energy Consumption for a 55 W PAR38, 2,500 hour HIR EL 1 Representative Lamp, Distribution of Dimmers Scenario With Lumens Equalized

EL	Annual Energy Consumption	
	Commercial	Residential
	<i>kWh</i>	<i>kWh</i>
Baseline	269.2	43.1
EL 1	247.3	40.1

Table 6A.4.8 Annual Energy Consumption for a 55 W PAR38, 4,200 hour Improved HIR EL 1 Representative Lamp, Distribution of Dimmers Scenario With Lumens Equalized

EL	Annual Energy Consumption	
	Commercial	Residential
	<i>kWh</i>	<i>kWh</i>
Baseline	269.2	43.1
EL 1	246.7	39.5

Table 6A.4.9 through Table 6A.4.10 present annual energy consumption in the Distribution of Dimmers scenario, in which lumen output for higher efficacy lamps is reduced by the same percentage lumen reduction that occurs at the baseline in the commercial and residential sectors.

Table 6A.4.9 Annual Energy Consumption for a 55 W PAR38, 2,500 hour HIR EL 1 Representative Lamp, Distribution of Dimmers Scenario With Percent Lumens Reduction

EL	Annual Energy Consumption	
	Commercial	Residential
	<i>kWh</i>	<i>kWh</i>
Baseline	269.2	43.1
EL 1	246.7	39.5

Table 6A.4.10 Annual Energy Consumption for a 55 W PAR38, 4,200 hour Improved HIR EL 1 Representative Lamp, Distribution of Dimmers Scenario With Percent Lumens Reduction

EL	Annual Energy Consumption	
	Commercial	Residential
	<i>kWh</i>	<i>kWh</i>
Baseline	269.2	43.1
EL 1	246.7	39.5

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APPENDIX 7A. ADDITIONAL END-USER PRICE RESULTS

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APPENDIX 7A. ADDITIONAL END-USER PRICE RESULTS

7A.1 INTRODUCTION

Because fluorescent lamps operate on a ballast in practice, DOE analyzed lamp-and-ballast systems in the engineering analysis. Therefore, in addition to developing end-user prices for lamps, the U.S. Department of Energy (DOE) also determined end-user prices for ballasts. These ballast prices were used as inputs in the life-cycle cost (LCC) analysis and the national impact analysis (NIA). This appendix presents the methodology DOE followed and the resulting fluorescent lamp ballast end-user prices.

7A.2 METHODOLOGY

To determine the end-user ballast prices in this rulemaking, DOE utilized information from the recent rulemaking for fluorescent lamp ballasts, finalized in 2011 (hereafter the “2011 Ballast Rule”). 76 FR 70548 (Nov. 14, 2011). In the 2011 Ballast Rule, DOE performed teardowns and a manufacturer markup analysis to develop manufacturer selling prices (MSPs) for representative ballast designs. DOE then applied distribution channel markups to derive end-user prices. See chapters 5 and 7 from the technical support document (TSD) for the 2011 Ballast Rule for more information.^a For this rulemaking, DOE utilized the end-user prices from the 2011 Ballast Rule to determine prices for replacement ballasts. Because the fluorescent ballast prices developed in the 2011 Ballast Rule were presented in 2009\$, DOE converted the end-user prices to 2012\$ by multiplying the 2009 prices by the ratio of the 2012 Consumer Price Index (CPI) to the 2009 CPI. Additionally, using historical data on the quantities and values of domestic shipments of fluorescent lamps, DOE examined product price trends, fitting the data to an experience curve. (See chapter 11 of this notice of proposed rulemaking (NOPR) TSD for further details.) DOE adjusted ballast prices using this experience curve.

DOE analyzed fixed light output ballasts in the engineering analysis and dimming ballasts in a lighting controls sensitivity. DOE developed different prices for each ballast type.

7A.2.1 Fixed Light Output Ballasts

As stated in chapter 5 of this NOPR TSD, for this rulemaking, DOE analyzed lamp-and-ballast systems with the same starting method and number of lamps as those analyzed in the 2011 Ballast Rule. In addition, because all ballasts selected by DOE comply with the standards adopted by the 2011 Ballast Rule, DOE assumed the prices of the representative ballasts in this rulemaking would be the same as the prices of the representative ballast units at the adopted efficiency level in the 2011 Ballast Rule.

Although DOE analyzed normal ballast factor (BF) ballasts as representative in the 2011 Ballast Rule, DOE also analyzed low BF ballasts in this rulemaking. Based on a review of blue

^a The TSD and other documents related to and supporting the 2011 Ballast Rule are available on regulations.gov, docket number EERE-2007-BT-STD-0016, at www.regulations.gov#!docketDetail;D=EERE-2007-BT-STD-0016.

book values and manufacturer feedback, DOE found that, in general, ballast prices for low and normal BF ballasts are very similar. Because the low BF replacement ballasts meet the efficiency level adopted by the 2011 Ballast Rule and DOE determined that low BF ballasts have the same prices as normal BF ballasts, DOE utilized the same end-user pricing for low BF ballasts as the representative ballast units at the efficiency level adopted in the 2011 Ballast Rule.

7A.2.2 Dimming Ballasts

Because most dimming ballasts are exempt from energy conservation standards,^b DOE did not analyze these ballasts in the 2011 Ballast Rule. Therefore, it was necessary to develop prices for the dimming ballasts analyzed in the lighting controls scenario of this rulemaking (see appendix 6A of this NOPR TSD for further details on the lighting control scenario). To determine prices for dimming ballasts, DOE compared the blue book prices of dimming ballasts to comparable fixed light output ballasts and developed a scaling factor to apply to the end-user prices of fixed light output ballasts developed in the 2011 Ballast Rule.

For the product classes analyzed in the lighting controls scenario (*i.e.*, 4-foot medium bipin (MBP), 4-foot T5 miniature bipin (MiniBP) standard output (SO), and 4-foot T5 MiniBP high output (HO) lamps in the commercial and industrial sectors), DOE matched commercially available fixed light output ballasts with a comparable dimming ballast offered by the same manufacturer. DOE considered ballasts with similar specifications, including starting method, maximum number of lamps operated, and efficiency, to be comparable. DOE calculated the percent difference in blue book prices for each pair of dimming and fixed light output ballasts. The average percent increase from fixed light output ballasts to dimming ballasts was 120 percent. Because DOE determined that programmed start (PS) fixed light output ballasts were the most similar to the dimming ballasts selected for this analysis, DOE applied a scaling factor of 2.2 to the end-user ballast prices developed for the 2-lamp PS 4-foot MBP, 4-lamp PS 4-foot MBP, 2-lamp PS 4-foot T5 MiniBP SO, and 2-lamp PS 4-foot T5 MiniBP HO systems.

7A.3 RESULTS

Table 7A.3.1 summarizes the fixed light output ballast prices. Table 7A.3.2 summarizes the dimming ballast prices.

^b Fluorescent lamp ballasts designed for dimming to 50 percent or less of its maximum output are exempt from standards with the exception of those listed in 10 CFR 430.32 (m)(10).

Table 7A.3.1 Fixed Light Output Ballast End-User Prices

Product Class	Diameter	Number of Lamps per Ballast	Starting Method	Ballast Factor Range		Ballast End User Price (2012\$, excluding sales tax)
4-foot MBP	T8	2	IS	Normal and Low	0.77 – 0.88	\$15.86
4-foot MBP	T8	2	PS	Normal and Low	0.72 – 0.88	\$17.06
4-foot MBP	T8	4	IS	Normal and Low	0.74 – 0.87	\$20.48
4-foot MBP	T8	4	PS	Normal	0.87 – 0.89	\$22.32
4-foot MBP (residential)	T8	2	IS	Normal	0.83 – 0.87	\$8.63
8-foot SP slimline	T8	2	IS	Normal and Low	0.77 – 0.87	\$18.86
8-foot RDC HO	T8	2	IS	Normal	0.81	\$15.04
4-foot T5 MiniBP SO	T5	2	PS	Normal	0.85 – 1.00	\$25.90
4-foot T5 MiniBP HO	T5	2	PS	Normal	1.00	\$27.11

Table 7A.3.2 Dimming Ballast End-User Prices

Product Class	Diameter	Number of Lamps per Ballast	Starting Method	Ballast Factor at Full Light Output	Ballast Factor at Minimum Light Output	Ballast End User Price (2012\$, excluding sales tax)
4-foot MBP	T8	2	PS	0.88	0.05	\$37.53
4-foot MBP	T8	4	PS	0.88	0.05	\$49.10
4-foot T5 MiniBP SO	T5	2	PS	1.00	0.01	\$56.99
4-foot T5 MiniBP HO	T5	2	PS	1.00	0.01	\$59.65

APPENDIX 7B. RARE EARTH PHOSPHOR MARKET ASSESSMENT AND IMPACT ON CONSUMERS

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APPENDIX 7B. RARE EARTH PHOSPHOR AVAILABILITY AND PRICING

7B.1 INTRODUCTION AND PURPOSE

The U.S. Department of Energy (DOE) has identified higher efficiency phosphors as a technology option that can be used to increase the efficacy of general service fluorescent lamps (GSFLs). (See chapter 3 of this notice of proposed rulemaking (NOPR) technical support document [TSD].) Specifically, the use of narrow-band rare earth phosphors (containing the rare earth elements yttrium[Y], europium [Eu], and terbium [Tb]) can improve lamp efficacy by increasing ultraviolet (UV) radiation absorption and emission of radiation in the visible spectrum relative to other phosphors. DOE is considering higher efficiency phosphors as a design option in this rulemaking.

Manufacturers expressed concern regarding higher GSFL standards because the limited rare earth availability (due to restrictions from China) would increase costs substantially. See the NOPR notice for more details on comments received. Depending on the lamp type, rare earth phosphors can be the highest input material cost of a GSFL. China, which as of 2012 was responsible for roughly 86 percent of worldwide rare earth production, has added tariffs and capped exports¹; the production quota in 2012 was about 95,000 tons, down 27 percent from 2010 when they produced about 130,000 tons and made up close to 98% of global production.^{1 2}

At the time of this analysis, many manufacturers^a had been granted exception relief exempting their 700 series T8 lamps from the standards adopted in a final rule published in July 2009 (requiring compliance in July 2012, hereafter “July 2012 standards”) for a period of two years. 74 FR 34080 (July 14, 2009). The waiver was granted due to the global supply restrictions on rare earth phosphors, the rising world demand of these phosphors, and the resulting impacts on producing higher efficacy GSFLs.³

DOE understands that supply and demand of rare earth phosphors should be considered when evaluating amended standards for GSFLs. Therefore, DOE is assessing the potential impact of standards that may result from this rulemaking on the requirement for rare earth phosphors and subsequent cost to the consumer. This appendix reflects DOE’s preliminary findings.

7B.2 RARE EARTH PHOSPHOR COMPOSITION

Rare earths are commercially defined to include 17 elements that have similar chemical properties. A small subgroup of these rare earth elements exhibit luminescence, some of which are critical to high-performance GSFLs. During the operation of common GSFLs, cathodes that

^a At the time of this analysis, the following manufacturers had been granted exception relief exempting their 700 series T8 lamps from current standards: Philips, GE, OSI, Ushio America, Halco Lighting Technologies, Premium Quality Lighting, Inc., Tailored Lighting, Inc., Litetronics International, Inc., Satco Products, Inc., DLU Lighting USA, Westinghouse Lighting Corporation, Ascent Battery Supply, LLC, Eiko, Ltd, Topaz Lighting Corporation, Technical Consumer Products, and Feit Electric Company.

seal each end of the lamp emit a flow of electrons that reacts with mercury vapor in the lamp and emits invisible UV radiation. To convert this UV radiation into visible light, manufacturers coat the inside of the lamp's glass with a fluorescent powder of blended elements, or phosphor. These phosphors generate visible light when struck by UV rays. In high-performance GSFLs, this phosphor blend includes rare earth materials.

The phosphor powders that manufacturers use in GSFLs can be divided into two groups: halophosphor blends and triband phosphor blends, the latter of which contain rare earth elements. Halophosphor blends are much less costly than those containing rare earth elements, but halophosphor blends are also less efficient and produce lower quality light. For some less efficacious GSFLs, manufacturers coat the lamp glass tubes with only halophosphor blends. However, fluorescent lamps now use three narrow-band rare earth phosphors (containing Y, Eu, and Tb) that emit light in the short, middle, and long wavelength ranges (*i.e.*, near 450, 550, and 610 nm⁴) of the visible spectrum. Lamps that meet the July 2012 standards predominately use triband phosphors; the more efficient fluorescent lamps exclusively use these triband phosphors.⁵ Coating a lamp with a layer of triband phosphors, in addition to or in place of halophosphors, increases efficacy while dramatically improving color quality and lumen maintenance. The precise blend and weight of the phosphor mixes also influence the color correlated temperature (CCT) and the color rendering index (CRI).

Generally, in high-performance GSFLs, manufacturers combine a blend of three rare earth phosphors: one that emits green light, one that emits red light, and one that emits blue light. These "triband" or "triphosphor" lamps require the use of varying amounts of rare earth elements (in addition to other elements) in the red, green, and blue phosphors. Specifically, there are five critical or near-critical rare earth elements that are commonly used in the triband phosphor blends: Y, Eu, Tb, lanthanum (La), and cerium (Ce). These elements work to emit light at the wavelengths to which human eyes are most sensitive. Y and Eu are used in the red phosphor; Tb, La, and Ce are common to the green phosphor; and Eu is used in the blue phosphor. Table 7B.2.1 displays general chemical formulas for each color phosphor (there are two common options for blue).

Table 7B.2.1 General Chemical Formulas for Key Phosphors

Phosphor Color	Chemical Formula
Red	Y ₂ O ₃ :Eu
Green	LaPO ₄ :Ce,Tb
Blue #1	BaMgAl ₁₀ O ₁₇ :Eu
Blue #2	(Sr,Ca,Ba) ₅ (PO ₄) ₃ Cl:Eu

After each color phosphor is manufactured, the phosphors are blended together for use in triband phosphor fluorescent lamps. The triband phosphor typically contains 60 percent rare earths by weight. The amount of rare earth material in each phosphor color can vary by manufacturer and application requirements. Table 7B.2.2 presents a breakdown of the average rare earth composition of triband phosphor.⁶

Table 7B.2.2 Average Rare Earth Phosphor Composition

Element	Total Rare Earth Content
Lanthanum	22.0%
Cerium	6.5%
Europium	4.5%
Terbium	5.0%
Yttrium	62.0%

Rare earth phosphor composition can vary, and manufacturers may optimize phosphor blends for certain results. One such example is the use of multimodal rare earth phosphors to lower rare earth phosphor associated costs for manufacturers. A multimodal rare earth phosphor consists of at least some relatively fine particles that fit in interstices between at least some relatively coarse particles.⁷ More efficient packing of the phosphors allows for reduced phosphor coating weight and thus rare earth phosphors are used more efficiently. Feedback from manufacturers in interviews indicated that multimodal phosphors are being utilized in commercially available lamps. Manufacturers noted that this particle-based technology does not actually increase the efficacy of a lamp but rather achieves that same efficacy using less rare earth phosphors. Therefore, according to manufacturer feedback received in interviews, the technology reduces the amount of phosphor used and thereby costs.

7B.3 SUPPLY CHAIN AND APPLICATIONS

Hundreds of mining firms, mostly in China, extract rare-earth-containing material from the ground. Rare earths are mined primarily from bastnäsite, monazite, and xenotime ores, as well as ion-adsorption clay. Naturally mixed in with many other elements, rare earths must be concentrated through a series of separation processes to distill the rare earth elements from the ore. Most of the mining firms also perform the initial stages of this concentration process. The two principal means of separating rare earths are solvent extraction and ion exchange, either of which can yield purities up to 99.999 percent.⁸ The most critical rare earths for lighting applications are Y, Eu, and Tb. Very high levels of purity (99.99 percent or greater) are necessary for these phosphors in lighting applications, which increases the cost to lamp manufacturers. One of the difficulties associated with processing rare earths such as Y, Eu, and Tb, is that achieving the required purity levels can be very expensive, requiring these mining companies to find markets for other materials beyond rare earths such as indium, gallium, and germanium. These byproducts are subject to large fluctuations in price, which can affect the market for the key rare earths for lighting as a result.⁹

The concentrated rare earth product is usually shipped to a handful of phosphor manufacturers who further process the rare earths to higher levels of purity and/or manufacture the phosphor. For lighting applications, the phosphor manufacturer may sell the individual colored phosphors or the mixed triband phosphor to lamp manufacturers. In other instances, lamp manufacturers may perform the phosphor blending in-house.

Rare earth materials, including phosphors, have found an increasing range of practical applications in recent decades. Aside from the energy efficiency applications, rare earths are

used in automotive catalysts, metals and magnets, petroleum catalysts, glass polishing, and ceramics. The industry has also experienced significant demand growth in recent years for use in electric and hybrid vehicles. In particular, Y and Eu are used in communication devices and as the red phosphor in televisions and liquid crystal displays (LCDs). Y is also used as a strength-enhancing additive to alloys of aluminum and magnesium and as an electrolyte component in fuel cells. Tb is utilized in electric motors and as an additive to neodymium-iron-boron permanent magnets. La and Ce are used as additives in fluid catalytic cracking processes for petroleum refining, and are also employed in nickel metal hydride batteries such as those found in hybrid and electric vehicles.^{10 11}

Figure 7B.3.1 shows the market breakdown of rare earth oxide^{b 12} demand in 2011.¹³ As of 2011, phosphors account for about 8 percent of rare earth demand. There are three main applications within this subgroup: televisions (plasma, LCD, and cathode ray tube), tri-band phosphor fluorescent lamps, and X-ray intensifying screens. Currently, there are few, if any, suitable substitutes in most applications, including high-efficiency GSFLs.

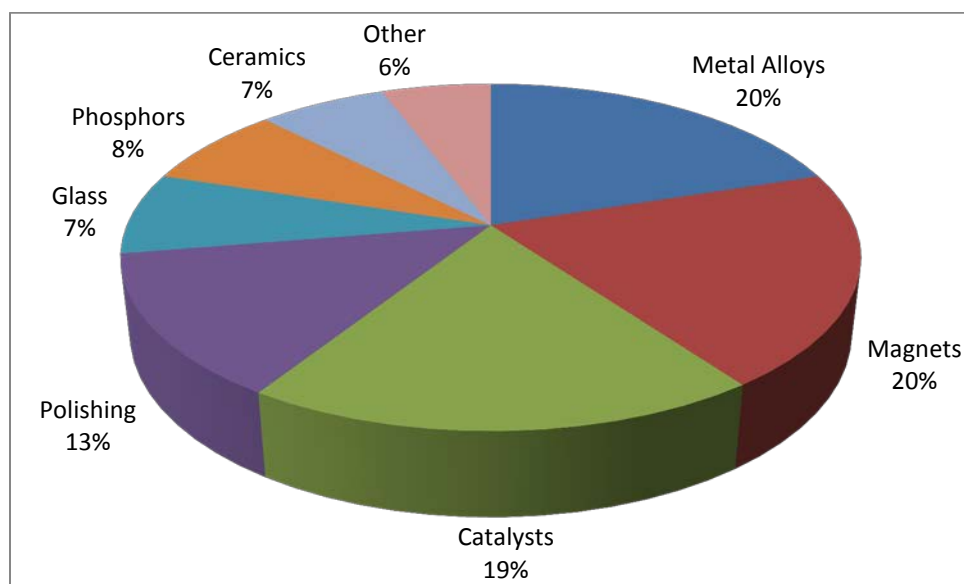


Figure 7B.3.1 Rare Earth Application by Volume

Source: Industrial Minerals Company of Australia, March 2012.

7B.4 RARE EARTH MARKET

Historically, unstable supply and demand and significant price fluctuations have been the norm in the rare earth market. The 1980s saw rapidly increasing demand, followed by substantial oversupply in the 1990s when China entered the market and quickly established a dominant market position.¹⁴ Prior to China's arrival as the dominant supplier of rare earths, most production came from the United States. By the late 1990s, China's low-cost supply had driven

^b Rare earth elements have a strong affinity for oxygen and therefore are mainly present as oxides and reported in terms of rare earth oxides.

down prices, causing many U.S. suppliers to cut or cease operations. China currently controls roughly 86 percent of the rare earth market and has continued to impose significant supply constraints through the use of export quotas and tariffs.¹⁵ Quota restrictions gradually increased in strictness between 2005 and 2011.¹⁶ However, quota restrictions since 2011 have remained fairly constant.¹⁷ Further, development of several large scale rare earth production facilities in the United States, Australia, and South Africa is expected by 2015. Major rare earth mining companies opening these new facilities include Molycorp, Great Western Minerals Group, Lynas Corporation, and Alkane Resources.¹⁸ Molycorp's mine in the United States and Lynas Corporation's mine in Australia are currently in operation and ramping up production.^{19 20} However, Great Western Minerals Group's mine in South Africa and Alkane Resources' mine in Australia are both still in development stages.^{21 22} In 2012, rare earth oxides were mined in the U.S. and domestic production totaled 7,000 tons, making the U.S. the second largest producer in the world.²³

Demand for rare earth phosphors is projected to grow rapidly through 2015. Trends towards greater energy efficiency and growth in compact fluorescent lamps (CFLs) are driving this increase in demand, though long-term forecasts indicate a slowing of this trend due to increasing prevalence of light-emitting diode (LED) lamps. Due to the unstable supply and demand, rare earth phosphor prices are currently extremely volatile, with price increases of up to 500 percent for Eu and Tb.²⁴ For additional information on the rare earth market, refer to the DOE Critical Materials Strategy (CMS)^c and the Decision and Order considering the Applications for Exception filed by Philips Lighting Company, GE Lighting, and OSRAM SYLVANIA, Inc. granted by the DOE Office of Hearing and Appeals.^d

7B.5 IMPACT OF STANDARDS

DOE recognizes significant price increases of rare earth phosphors are likely given the actions of China and expected increase in demand. Therefore, DOE conducted a sensitivity analysis to address the potential increases in end-user lamp prices attributable to greater phosphor input costs. DOE calculated the LCC savings under scenarios with higher phosphor prices. Additionally, in the national impact analysis (NIA), DOE conducted a sensitivity analysis that evaluated the impact of rare earth phosphor prices by developing shipment scenarios based on volatile and reference prices of rare earth phosphors. (See chapters 11, 12, and appendix 11B of this NOPR TSD for further details of this analysis.)

To analyze the impact of higher phosphor prices on the consumer, DOE calculated the LCC savings from purchasing higher efficacy GSFLs in a scenario with higher phosphor prices. For this analysis, DOE assumed that the cost of the lamp to the end-user would need to increase until LCC savings reached zero before the cost of rare earth phosphors negatively impacted consumer savings. Because the LCC savings represent savings to the end-user, DOE divided

^c U.S. Department of Energy. *Critical Materials Strategy*. December 2011. Accessible here: http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf.

^d *Philips Lighting Company, et al.* OHA Case Nos. EXC-12-0001, EXC-12-0002, EXC-12-0003 (2012). Accessible here: <http://energy.gov/sites/prod/files/oha/EE/EXC-12-0001thru03.pdf>.

LCC savings by the markup used in the manufacturer impact analysis to determine how much the rare earth phosphor manufacturing cost would impact the end-user. DOE assumed that this cost increase would be attributable only to the increase in the cost of rare earth phosphors.

DOE determined the quantity of rare earth phosphor required to achieve the desired efficacy of GSFLs in each product class (*i.e.*, by lamp type). DOE then determined the cost of the rare earth phosphors to the manufacturers considering the quantity of each phosphor required and the current estimated cost of each phosphor type. DOE calculated that the average cost per weight to manufacturers of rare earth phosphor used in the fluorescent lamps covered is approximately \$0.10 per gram at current phosphor prices. For more information on the calculation of the quantities of rare earth phosphor and derivation of prices, see appendix 9B of this NOPR TSD. Next, by applying manufacturer and retail markups, DOE analyzed how much this rare earth phosphor cost could increase before LCC savings would reach zero for each efficacy level (EL). DOE focused on ELs that had been determined to result in positive LCC savings.

For the 2-lamp instant start (IS) system pairing in the 4-foot medium bipin (MBP) product class, phosphor prices could increase more than 18 times before LCC savings reach zero at EL 1. Phosphor prices could increase at least 2.6 times before any positive LCC savings reach zero at EL 2. For the 2-lamp programmed start (PS) system pairing in the 4-foot MBP product class, phosphor prices could increase more than 32 times before any positive LCC savings reach zero at EL 1. Phosphor prices could increase more than 13 times before any positive LCC savings reach zero at EL 2.

For the 4-lamp IS system pairing in the 4-foot MBP product class, phosphor prices could increase more than 16 times at EL 1 and at least two times at EL 2 before any positive LCC savings reach zero. For the 4-lamp PS system pairing in the 4-foot MBP product class, phosphor prices could increase at least 1.8 times before any positive LCC savings reach zero at EL 1. Phosphor prices could increase more than 13 times before any positive LCC savings reach zero at EL 2 for the reduced wattage representative lamp units. Consumers already face negative LCC savings at EL 2 for the full wattage representative lamp units for the 4-lamp PS system.

In the residential sector, for the 2-lamp IS system pairing in the 4-foot MBP product class, phosphor prices could increase more than 15 times before any positive LCC savings reach zero at EL 1. Phosphor prices could increase at least 1.1 times before any positive LCC savings reach zero at EL 2 for the reduced wattage representative lamp units. Consumers already face negative LCC savings at EL 2 for the full wattage representative lamp units for the 2-lamp IS system in the residential sector.

For 8-foot single pin slimline lamps, phosphor prices can increase more than nine times before any positive LCC savings reach zero at EL 1. Phosphor prices could increase at least 1.7 times before any positive LCC savings reach zero at EL 2. For 8-foot recessed double contact high output (HO) lamps, consumers already experience negative LCC savings at EL 1 and EL 2.

For 4-foot T5 miniature bipin (MiniBP) standard output lamps, phosphor prices could increase at least 19 times before any positive LCC savings reach zero at EL 1. Phosphor prices

could increase at least 1.2 times before any positive LCC savings reach zero at EL 2. DOE determined that for 4-foot T5 MiniBP HO lamps, phosphor prices can increase more than 15 times before any positive LCC savings reach zero at EL 1 for the reduced wattage representative lamp units. Consumers already experience negative LCC savings at EL 1 for the full wattage representative unit.

Based on the analysis above, DOE concludes that the proposed ELs for GSFLs in this rulemaking are achievable even with potential variability in rare earth phosphor prices. DOE will, however, continue to examine the impacts of rare earth phosphor availability in relation to standards for GSFLs during the course of this rulemaking.

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APPENDIX 7C. XENON MARKET ASSESSMENT AND IMPACT ON CONSUMERS

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APPENDIX 7C. XENON AVAILABILITY AND PRICING

7C.1 INTRODUCTION

The U.S. Department of Energy (DOE) has identified higher efficiency inert fill gas as a technology option that can be used to increase the efficacy of incandescent reflector lamps (IRLs). (See chapter 3 of this notice of proposed rulemaking (NOPR) technical support document [TSD].) The low thermal conductivity of higher efficiency inert fill gases allows the lamp to operate at higher temperatures, increasing lamp efficacy. Further, the gases' large mass slows the evaporation of tungsten, lengthening lamp lifetime.

The price of xenon has fluctuated considerably in past years and, although the price has recently been stable, the demand of xenon is expected to increase while supply remains limited. Therefore, DOE has conducted an in-depth market assessment of the supply of xenon and analyzed the potential impact of xenon supply limitations on IRL standard levels. DOE also conducted a life-cycle cost (LCC) sensitivity analysis to determine the impact of higher xenon prices on the consumer. DOE determined that the supply of xenon is sufficiently large and will not affect IRL product availability, and therefore has maintained the use of xenon as a design option. This appendix reflects DOE's preliminary findings.

7C.2 SUPPLY

Xenon is one of three rare gases (along with neon and krypton) produced by cryogenic air separation. Given the low concentration of the rare gases in the air (neon 0.0018 percent by volume, krypton 0.00011 percent by volume, and xenon 0.000087 percent by volume), the only cost-effective recovery option is a large air separation unit (ASU). ASU xenon recovery is an inherently costly process due to the low volume content of xenon in air. The lower the concentration, the greater the purification cost per liter of rare gas. In February 2013, CryoGas reported that world production of xenon was roughly 9.8 million liters in the previous year (2012) and estimated it to increase in 2013.¹ Most worldwide supply is met by the four largest industrial gas companies: Praxair, Inc. (Praxair), Air Liquide, The Linde Group (Linde), and Iceblick, Ltd. (Iceblick). Together these four companies control about 75 percent of global rare gas sales. The remaining 25 percent is from various steel mills and industrial gas companies in Russia and China. Figure 7C.2.1 displays the xenon production relative market share of the four main companies.

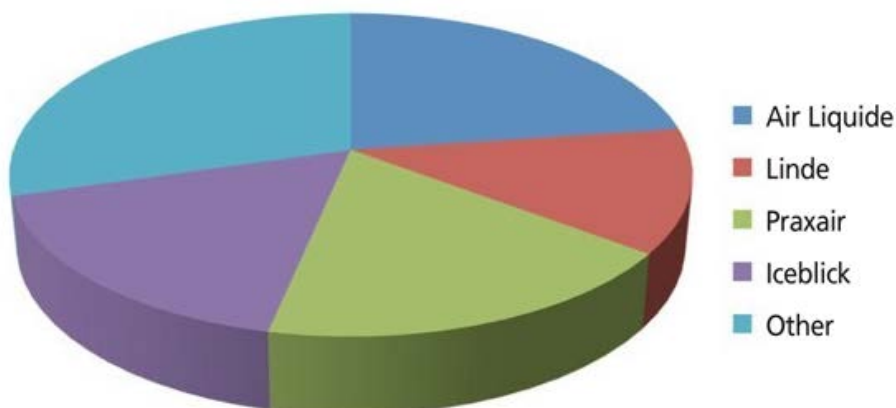


Figure 7C.2.1 Xenon Market Share by Key Supplier

Source: Betzendahl Gas Consultant LLC, February 2012

The supply of global rare gases has been generally constant in recent years. The small amount of new production capacity growth has been mainly concentrated in China. Eastern Europe is the largest producer of a crude krypton-xenon gas mixture (hereafter “Kr/Xe”), with an estimated 33 million liters produced yearly.² Xenon comprises 10 percent of Kr/Xe.³ Together, China and the Pacific Rim are the second largest producer of Kr/Xe worldwide, roughly 70 percent of which is in China, a region where continued growth of ASU projects is expected.^a

7C.2.1 Key Players

7C.2.1.1 Praxair

With 26,500 employees and operations in more than 50 countries, Praxair posted annual sales of \$11.22 billion in 2012.⁴ Within Praxair’s industrial gases business, its primary products are atmospheric gases (argon, nitrogen, oxygen, rare gases) and process gases (carbon dioxide, helium, hydrogen, electronic gases, specialty gases, acetylene). Praxair is also one of the four major industrial gas companies and a significant supplier of xenon. A 2011 report estimated that the United States was producing roughly 13 million liters of crude Kr/Xe; Praxair controlled 85 percent of total U.S. production.⁵

7C.2.1.2 Air Liquide

With more than 46,200 employees in 80 countries, Air Liquide reported revenues totaling 15.3 billion euros in 2012, an increase of over 6 percent from 2011. The gas and services group of the company is responsible for about 91 percent of the total 2012 revenue with group revenue of around 13.9 billion euros in 2012.⁶ Besides manufacturing industrial grade xenon, Air Liquide supplies medical gases (oxygen, nitrous, oxide, nitric oxide, xenon, etc.) to hospitals and clinics worldwide and continues to invest in research and development for new medical applications. In a March 2011 report, it was estimated that Western Europe produces around 19 million liters of

^a Note: Crude Kr/Xe is a rare gas mixture that is a byproduct of ASU processes.

crude Kr/Xe,⁷ and nearly 100 percent of this production was under control by Air Liquide and Linde. The report also estimated that total production in the Middle East and South Africa of crude Kr/Xe was roughly 15 million liters. In a joint venture with Sasol, Air Liquide produced nearly 10 million liters of crude Kr/Xe from a coal gasification plant in South Africa, about 30 percent of which was xenon.

7C.2.1.3 Linde

Based in Germany, Linde has approximately 62,000 employees working in over 100 countries. In 2012, Linde achieved sales of 15.3 billion euros, an increase of just under 11 percent from 2011.⁸ Linde supplies a large range of compressed and liquefied gases on the international market to a variety of industries. Linde has continued investing in medical gas solutions research and development as part of their rapidly expanding healthcare business. Linde also is a major manufacturer of xenon and is the only one of the four major suppliers that is adding significant production capacity, with much of the production capacity growth to be in China.^{9 10}

7C.2.1.4 Iceblick

Iceblick is a collaboration of companies in Kazakhstan, Russia, Ukraine, and the United States. Asserting themselves as a global market leader for gas products, Iceblick produces about 60 percent of the world's supply of neon and over 20 percent of global krypton and xenon.¹¹ It obtains its raw materials from chemical companies based in Russia, Ukraine, Kazakhstan, and Romania. Iceblick sources raw material from local industries and purifies the gases to sell the gas products to their corporate consumers, which are predominantly industrial gas companies but also include the laser, electronic, lighting, and medical industries. According to a March 2011 report by CryoGas, Eastern Europe is the largest supplier of crude Kr/Xe with a total production of approximately 33 million liters per year.¹² Iceblick controlled 70 percent of this total production. Iceblick is also the second biggest global producer of high purity xenon.¹³

7C.2.2 Applications

Xenon applications include lighting, the medical industry, the space industry, and the electronics industry, which are described in more detail in the following sections.

7C.2.2.1 Lighting Industry

One of the most common applications for rare gases, in particular krypton and xenon, is lighting. Using xenon as a fill gas in incandescent lamps increases the life of the filament and slows down its progressive deterioration, thereby increasing the lamp's efficacy.¹⁴ Xenon is also used in neon tubes for signage applications. In the automotive industry, xenon-filled headlights are used as a less expensive substitution for high-intensity discharge (HID) lamps and comply with federal legislation on vehicle safety.¹⁵ Additional lighting applications of xenon include pulse light sources, ultraviolet lamps, and X-ray lamps.

Demand for xenon in the lighting industry may be greater in the next few years. Incandescent light bulbs will be phased out by federal regulations in 2014. Replacement options include compact fluorescent lamps (CFLs), halogen incandescent lamps, or light-emitting diodes (LEDs). CFLs and halogen incandescent lamps both use rare gases. Fluorescents use krypton and xenon, while halogen incandescent lamps use xenon.¹⁶ LED production also uses a large amount of gases, however, not krypton or xenon.¹⁷ By 2015-2016, xenon use in lighting is expected to decline due to the lighting industry transitioning to LEDs.¹⁸

7C.2.2.2 Medical Applications

Xenon's anesthetic properties were first discovered in 1939, though it was not used as a medical anesthetic until 1951.¹⁹ Its use as an anesthetic had been largely forgotten until about 1990, mainly because of the high cost.²⁰ Since that time, there has been a large amount of research devoted to analyzing the pros and cons of using xenon. The first large-scale study that evaluated the use of xenon anesthesia in humans concluded that xenon is at least equivalent to nitrous oxide-isoflurane in efficacy and safety.²¹ Compared to nitrous oxide, xenon's other benefits include a faster recovery time and environmental friendliness. High cost is the only obstacle prohibiting xenon from widespread use as an anesthetic. Currently, xenon recovery in medical applications is necessary for xenon to remain cost-effective. Pending approval for xenon use in anesthesia in the European Union (EU), this application of xenon may expand from a few hundred thousand liters to a few million liters annually by 2015-2016.²²

Besides its use in anesthesia, xenon is also used in the medical industry to enhance imaging in X-rays, computer axial tomography (CAT) scans, and magnetic resonance images (MRIs). Xenon makes it possible to obtain better X-rays with reduced amounts of radiation. Additionally, when mixed with oxygen, xenon enhances contrast in computed tomography (CT) imaging and can be used to determine blood flow.²³

Demand for xenon for use in medical lasers has continued to grow, even during the recession.²⁴ The growth in laser applications is mainly due to heightened demand in medical markets, which have experienced strong growth as a whole on a global scale.²⁵ Ultraviolet and excimer lasers (for eye surgery) utilize xenon and are the fastest growing segment of the laser industry.²⁶ More recently, there has been increased research into using medical gases, including xenon, in the field of neurobiology to exploit their potentially therapeutic use on a variety of brain diseases.²⁷

7C.2.2.3 Space Industry

Xenon is used in the space industry for ion engines and ion plasma thrusters for satellites. Ion engines depend on electrically charged atoms to generate thrust. While not as powerful, they are ten times more efficient than alternative chemical propulsion systems. Using xenon reduces the required propellant mass by up to 90 percent, thereby reducing launch costs due to a lighter spacecraft.²⁸ Newer satellites use xenon ion propulsion systems, which usually have four ion engines, for repositioning. Xenon is well suited for this application because it is easy to ionize, has a high density, and low heat capacity. In addition, its high molecular weight boosts the

satellites impulse performance.²⁹ The global satellite industry grew 5 percent in 2011,³⁰ with future growth of this market continuing to increase as satellite programs grow worldwide.

7C.2.2.4 Semiconductor Industry

Xenon gas mixtures are used in plasma display panels (PDPs) and televisions to improve luminescence, performance, and energy use.³¹ PDPs are commonly used for large TV screens and compete directly with liquid crystal displays (LCDs). In PDP technology, xenon and neon gas is contained in many tiny cells between two glass plates. Electrically charging the electrodes, which are installed between the glass plates, ionizes the gas and forms plasma. Photons emitted by the plasma excite the phosphors coating the back of each cell, emitting colored light.³² Thus, the operation of each cell is similar to that of a fluorescent lamp. The flat panel plasma TV market share is expected to decrease to roughly 5 percent in 2012 and to keep declining in future years. LCD and LED panels will continue to gain market share.³³ An organic light-emitting diode (OLED) flat panel display is a more recent technology than LED flat panels and does not require a back light. Active matrix OLED (AMOLED) displays used in cellular phones and TVs are experiencing rapid market growth, especially in smart phones, with 90 million units sold in 2011, a 97 percent increase from 2010.³⁴ Their share of the market is expected to continue to increase rapidly in the next few years. While AMOLED technology does not use large amounts of xenon, if its popularity continues to increase as projected, the amount of xenon required could become significant.³⁵

Xenon is also used in electronic chip manufacturing. Companies utilize xenon plasma etching to manufacture micro-electro-mechanical systems (MEMS).³⁶ Demand from the electronics industry increased from under one million liters of xenon per year to almost three million liters per year prior to the 2008 recession. However, it decreased back down to one million between 2008 and the end of 2009 due to the recession.³⁷ Air Products, an industrial gas company, introduced a xenon recovery system for the semiconductor and MEMS industries in 2009.³⁸ Air Products subsequently developed two additional systems: one for larger volumes and one for higher concentrations. The latter system is useful for applications, such as lighting, where the xenon is available in high concentrations. The xenon recovery technology uses vacuum swing absorption to extract xenon from process effluent streams. A mixture containing high levels of xenon is recovered and sent offsite for distillation once storage vessels are full. Air Products estimates customers could save up to 67 percent on the cost of xenon.³⁹

7C.3 PRICE

Xenon pricing is affected by supply and demand dynamics, which are impacted by global production capacity, as well as the trends in the markets or industries they serve. Figure 7C.3.1 tracks and forecasts xenon supply and demand.⁴⁰ Global production of xenon was around 9.8 million liters in 2012, while the total rare gas market was around \$250 million according to the 2012 CryoGas report. This is forecasted to keep growing through 2016. As seen in Figure 7C.3.1, xenon demand has been on a steady rise since its lowest point in 2010, driven by growth in the lighting and satellite markets.⁴¹ Demand for xenon is projected to increase by at least 10 percent in 2013-2014, followed by a stagnation as LEDs become more prevalent in the lighting industry.⁴² The price for xenon fell roughly 75 percent from its 2008 peak of about \$25 per liter

to about \$7 per liter in 2010, for large users.⁴³ The 2013 CryoGas Report stated that xenon prices were flat in 2012.⁴⁴ Additional data indicated that xenon was about \$10 per liter in 2012.⁴⁵ The price of xenon is highly dependent on demand for the major applications previously discussed in section 7C.2.2. Approval of xenon use in anesthesia in the EU may lead to more dramatic price increases in 2015 and beyond.⁴⁶

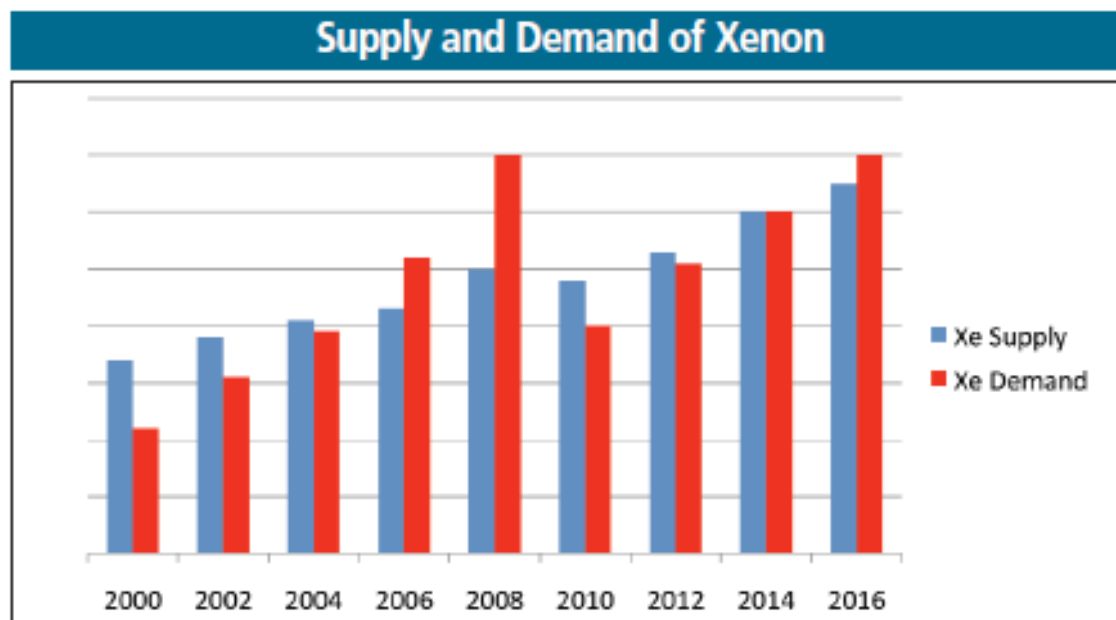


Figure 7C.3.1 Xenon Supply and Demand

Source: Betzendahl Gas Consultant LLC, February 2013

7C.4 IMPACT OF STANDARDS

DOE recognizes fluctuations in the price of xenon are possible. Therefore, DOE conducted a sensitivity analysis to address the potential increases in end-user lamp prices attributable to an increased price of xenon. DOE calculated LCC savings under scenarios with higher xenon prices. A more detailed description of DOE's methodology and assumptions follows. Additionally, in the national impact analysis (NIA), DOE conducted a sensitivity analysis that evaluated the impact of an increased xenon price. (See chapters 11 and 12 of this NOPR TSD.)

DOE performed an analysis to determine how much the price of xenon could increase before it negatively impacted LCC savings. DOE assumed that the cost of the efficacy level (EL) 1 lamp to the end-user would need to increase until LCC savings reached zero before the cost of xenon impacted consumer savings. Because the LCC savings represent savings to the end-user, DOE divided LCC savings by the markup used in the manufacturer impact analysis. DOE assumed that this increase in manufacturing cost would be attributable only to the increase in the cost of xenon. Through manufacturer interviews, DOE estimated the quantity of xenon that would be required to achieve the desired efficacy in an individual lamp. DOE determined the

cost of xenon using publicly available xenon pricing data. DOE calculated that the average cost to manufacturers of xenon used in the IRLs is approximately \$10 per liter. Using this information and applying manufacturer and retail markups, DOE was able to calculate how much the price of xenon could increase before LCC savings would reach zero for each EL.

DOE analyzed the effect of xenon price on LCC savings, as discussed above, for EL 1 in the commercial and residential sectors. For the 55 W PAR38 2,500-hour HIR representative lamp in the commercial sector, the price of xenon could increase to over \$242 per liter, an increase at least 24 times before LCC savings reach zero. For the 55 W PAR38 2,500-hour halogen-infrared (HIR) representative lamp in the residential sector, the price of xenon would have to exceed \$178 per liter, an increase of more than 17 times, before LCC savings reach zero. For the 55 W PAR38 4,200-hour improved HIR representative lamp in the commercial sector , the price of xenon would have to exceed \$686 per liter, an increase of more than 68 times, before LCC savings reach zero. For the 55 W PAR38 4,200-hour improved HIR representative lamp in the residential sector, the price of xenon would have to exceed \$447 per liter, an increase of more than 44 times, before LCC savings reach zero.

Based on the analysis above, DOE concludes that EL 1 is achievable even with potential variability in xenon prices. DOE will continue to examine the impacts of xenon availability in relation to standards for IRLs during the course of this rulemaking.

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APPENDIX 8A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

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APPENDIX 8A. USER INSTRUCTIONS FOR LIFE-CYCLE COST AND PAYBACK PERIOD SPREADSHEETS

8A.1 INTRODUCTION

It is possible to examine and reproduce the detailed results of the life-cycle cost (LCC) and payback period (PBP) analyses using Microsoft Excel® spreadsheets available on regulations.gov, docket number EERE-2011-BT-STD-0006 at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006. Running the spreadsheet sample calculations requires Microsoft Excel. Additionally, Crystal Ball® software is required to run the Monte Carlo simulations. Both applications are commercially available. Crystal Ball is available at www.decisioneering.com.

The spreadsheet posted on regulations.gov represents the latest version of the LCC and PBP analysis model. It has been tested with Microsoft Excel 2010 and Crystal Ball 11.1.2.2.

8A.2 LIFE-CYCLE COST AND PAYBACK PERIOD WORKBOOK

The LCC and PBP spreadsheet or workbook consists of the following worksheets:

LCC Summary (Sum)	Contains the input selections and a summary table including energy use, operating costs, installed costs, LCC, LCC savings, and PBP for each selection. This worksheet also works as an interface between user inputs and the rest of the worksheets.
Import Parameters (Para)	Contains the engineering analysis, as well as all parameters imported into the LCC Summary page. Tables of results are only relevant for the lamp type and/or product class selected by the user.
Lighting Controls (Cont)	Contains relevant statistics and assumptions regarding the prevalence and lumen reduction of lighting controls, as well as their effects on energy usage and lamp lifetime.
Learning Curve (Learn)	Contains the data to account for learning curve adjustments to the installed price and tables displaying installed prices adjusted for learning curves and rare earth factors for each product during each year.
Annual Cash Flow (Cash)	Contains tables of the equipment costs, operating costs, and total discounted costs in each year, as well as tables detailing the years that require a lamp or ballast replacement. Tables are only relevant for the lamp type and/or product class selected by the user.

Assumptions and Inputs (Assump)	Includes sales tax data, population data, labor costs, disposal costs, rare earth scenario values, ballast data (lifetimes, lamps per ballast, learning curve correction factor), lifetimes used to calculate the analysis period, and the percent mean versus initial lumens for incandescent reflector lamps (IRLs).
Electricity Prices (EPrices)	Contains reference year electricity prices for the sampled households and Consumer Price Index values for scaling.
Electricity Trends (EPriceTrend)	Contains the electricity price trends for the reference-, high-, and low-economic-growth scenarios based on the U.S. Energy Information Administration's <i>Annual Energy Outlook 2013</i> .
Discount Rates (DRates)	Contains data from which an average discount rate and a distribution of discount rates are determined.
Commercial Op. Hours (ComOH)	Contains Commercial Building Energy Consumption Survey data and 2010 US Lighting Market Characterization (2010 LMC) data from which average commercial operating hours and a distribution of commercial operating hours for each lamp type are determined.
Residential Op. Hours (ResOH)	Contains Residential Energy Consumption Survey data and 2010 LMC data from which average residential operating hours and a distribution of residential operating hours for each lamp type are determined.
Industrial Op. Hours (IndOH)	Contains Manufacturing Energy Consumption Survey data and 2010 LMC data from which average industrial operating hours and a distribution of industrial operating hours for each lamp type are determined.

8A.3 BASIC INSTRUCTIONS

Basic instructions for operating the LCC spreadsheets are as follows:

1. Once you have downloaded the LCC spreadsheet file from the web, open the file using Excel. Click on the tab for the worksheet named Sum.
2. Use Excel's "View/Zoom" commands at the top menu bar to change the size of the display to make it fit your monitor.
3. Interact with the spreadsheet by clicking choices or entering data using the interface on the worksheet named Sum. Select choices from the various inputs listed under the "User Input" heading.

4. Under the “User Input” heading, select choices from the selection buttons and boxes for the following: (1) Type of calculation (Sample Calculation or Crystal Ball), (2) Lamp Type, (3) Product Class, (4) Baseline Lamp (for general service fluorescent lamps [GSFLs]) or EL 1 Representative Unit (for IRLs), (5) Sector, (6) Number of Lamps, (7) Ballast Type, (8) Electricity Price Trend, (9) Start Year, (10) Learning Curve (11) Multiple of Baseline Service Life (for Analysis Period), (12) Lamp Price, (13) Ballast Price, (14) Rare Earth Scenario, (15) Residential Lamp Preservation (select lamp preservation Avg. Op Hours or High Op. Hours scenario, and select user-specified Remaining Fixture Life at AP Start), (16) Operating (Op.) Hrs Sensitivity (Low Op. Hours or High Op. Hours), (17) New Construction Spacing (No spacing adjustments or spacing adjustments), (18) Base Case Dimmer Selection (No Base Case Dimmers or Base Case Dimmers), (19) Equalize Lumens Selection (Equalize Lumens at Each Level or Dim By Same Percentage at Each Level), (20) Lifetime Selection (Normal or Shortened), and (21) LCC Subgroup (No Subgroup, Institutions that Serve Low-Income Populations [for the commercial sector], or Low Income Consumers [for the residential sector]).
5. To change inputs listed under “User Input,” select the input you wish to change by either clicking on the appropriate button/checkbox or selecting the appropriate input from the input box.
6. This spreadsheet gives the user two types of calculation methods:
 - a. If “Sample Calc” is selected, then all calculations are performed for single-input values, usually an average. The new results are shown on the LCC Summary worksheet as soon as the new values are entered.
 - b. Alternately, if “Crystal Ball” is selected, the spreadsheet generates results that are distributions. Some of the inputs are also distributions. The results from the LCC distribution are shown as single values and refer only to the results from the last Monte Carlo sample, and are therefore not meaningful. To run the distribution version of the spreadsheet, the Microsoft Excel add-in software called Crystal Ball must be enabled.

To produce sensitivity results using Crystal Ball, simply select Start from the Run menu (on the Crystal Ball toolbar). To make basic changes in the run sequence, including altering the number of trials, select Run Preferences from the Run menu. After each simulation run, the user needs to select Reset (also from the Run menu) before Start can be selected again. Once Crystal Ball has completed its run sequence, it will produce a series of distributions. Using the Analyze menu on the Crystal Ball Excel tab, it is possible to obtain further statistical information. The time taken to complete a run sequence can be reduced by minimizing the Crystal Ball window in Microsoft Excel. The following outlines a step-by-step summary of the procedure for running a distribution analysis:

1. Find the Crystal Ball toolbar (at top of screen)
2. Click on Start from the Run menu bar

3. Select Run Preferences and choose from the following choices:
 - a. Monte Carlo (recommended)
 - b. Latin Hypercube
 - c. Initial seed choices and whether or not to be constant between runs^a
 - d. Select number of Monte Carlo Trials (1,000 was used for this analysis)
4. To run the simulation, select the green right arrow (“Start Simulation”) button on the Crystal Ball toolbar or select “Start Simulation” from the Run menu.
5. Wait until the program informs you that the simulation is completed. Note that to run a new simulation, “Reset Simulation” must first be selected from the Crystal Ball toolbar or Run menu.

The following instructions are provided to view the output generated by Crystal Ball.

1. After the simulation has finished, to see the distribution charts generated, select the Crystal Ball window in the Windows task bar.
2. The LCC savings and PBPs are defined as Forecast cells. The frequency charts display the results of the simulations, or trials, performed by Crystal Ball. Click on any chart to bring it into view. The charts show the low and high endpoints of the forecasts. The View selection on the Crystal Ball toolbar for each chart can be used to specify whether you want cumulative or frequency plots shown.
3. To calculate the certainty that the LCC savings will be above a particular value, either type that value in the box by the left arrow at the bottom of the chart window, or move the arrow key with the cursor to that value on the scale. The value in the Certainty box shows the likelihood that the LCC savings will be above that value. To calculate the certainty of the PBP being below a certain number of years, choose that value as the high endpoint.
4. To generate a printout report, select Create Report from the Analyze menu and then select the charts and statistics that you are interested in. For further information on Crystal Ball outputs, please refer to Understanding the Forecast Chart in the Crystal Ball manual.
5. To determine an average of the results reported by Crystal Ball for a forecasted value, select Extract Data from the Analyze menu and calculate the average of the trial values reported for that variable.

^a Because of the nature of the program, there is some variation in results due to random sampling when Monte Carlo or Latin Hypercube sampling is used. The same sequence of random numbers should be used to reproduce results consistent with the presented values. To do this, select “Use same sequence of random numbers” and an initial seed value of 999 in the sampling tab.

APPENDIX 8B. SUPPLEMENTARY LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

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APPENDIX 8B. SUPPLEMENTARY LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

8B.1 INTRODUCTION

This appendix discusses uncertainty and variability analyses and presents results of those uncertainty and variability analyses performed in the life-cycle cost (LCC) and payback period (PBP) analysis. The Monte Carlo analysis presents results for the LCC and PBP analyses using a distribution of operating hours, discount rates, sales tax, and electricity prices. The average LCC savings at each efficacy level (EL) for each lamp or lamp-and-ballast design is given along with the percentage of consumers who would experience a net benefit or net loss by purchasing a standards-case design instead of a base-case design. The median and mean PBP are also given. This appendix also presents results of the LCC and PBP analysis using high and low lamp prices and using high- and low-economic-growth electricity price trends based on Energy Information Administration's (EIA's) *Annual Energy Outlook 2012* (AEO 2013) datasets.

For residential incandescent reflector lamps (IRLs), results using high operating hours (986 hours/year: the average operating hours of a lamp placed in the exterior of a single-family attached or multifamily home) and low operating hours (329 hours/year: the average operating hours of a lamp placed in a location in the other/unknown category of a multifamily or mobile home) are presented. These operating hours were obtained from the 2010 U.S. Lighting Market Characterization.¹ For IRLs, DOE also conducted a sensitivity analysis to account for the scenario in which manufacturers would produce lamps with a shorter lifetime than the baseline lamps in order to increase efficacy. For general service fluorescent lamps (GSFLs), an additional sensitivity analysis was conducted to analyze the impacts of volatile rare earth oxide costs on future lamp prices.

Results are also presented from several scenarios assessing the impacts of lighting controls. The effect of an individual consumer owning a dimmer is presented for GSFLs and IRLs. The effect of a distribution of dimmers across the population is presented for IRLs.

8B.2 INTRODUCTION TO UNCERTAINTY AND VARIABILITY

Analysis of an energy-efficiency standard involves calculations of impacts, such as the impact of a standard on consumer LCC. In order to perform the calculation, the analyst must first: 1) specify the equation or model that will be used; 2) define the quantities in the equation; and 3) provide numerical values for each quantity. In the simplest case, the equation is unambiguous (contains all relevant quantities and no others), each quantity has a single numerical value, and the calculation results in a single value. However, in almost all cases, the model and/or the numerical values for each quantity in the model are not completely known (*i.e.*, there is uncertainty) or the model and/or the numerical values for each quantity in the model depend upon other conditions (*i.e.*, there is variability). Explicit analysis of uncertainty and variability is intended to provide more complete information for the decision-making process.

8B.3 UNCERTAINTY

When making observations of past events or speculating about the future, imperfect knowledge is the rule rather than the exception. For example, the energy actually consumed by a particular appliance type (such as the average U.S. lamp) is not directly recorded, but rather estimated based upon available information. Even direct laboratory measurements have some margin of error. When estimating numerical values expected for quantities at some future date, the exact outcome is rarely known in advance.

8B.4 VARIABILITY

Variability means that different applications or situations produce different numerical values when calculating a quantity. Specifying an exact value for a quantity may be difficult because the value depends on something else. For example, the number of hours a lamp is operated by a household depends upon the specific circumstances and behaviors of the occupants (*e.g.*, number of persons, personal habits about how much light the person needs). Variability makes specifying an appropriate population value more difficult in as much as any one value may not be representative of the entire population. Surveys can be helpful here, and analysis of surveys can relate the variable of interest (*e.g.*, hours of use) to other variables that are better known or easier to forecast (*e.g.*, persons per household).

8B.5 APPROACHES TO UNCERTAINTY AND VARIABILITY

This section describes two approaches to uncertainty and variability: scenario analysis and probability analysis.

Scenario analysis uses a single numerical value for each quantity in a calculation, then changes one (or more) of the numerical values and repeats the calculation. A number of calculations are done, which provide some indication of the extent to which the result depends upon the assumptions. For example, the LCC of a lamp could be calculated for energy rates of 2, 8, and \$0.14 per kilowatt-hour (kWh).

The advantages of scenario analysis are that each calculation is simple; a range of estimates is used; and crossover points can be identified. (An example of a crossover point is the energy rate above which the LCC is reduced, holding all other inputs constant. That is, the crossover point is the energy rate at which the consumer achieves savings in operating expense that more than compensate for the increased purchase expense.) The disadvantage of scenario analysis is that there is no information about the likelihood of each scenario.

Probability analysis considers the probabilities within a range of values. For quantities with variability (*e.g.*, electricity rates in different households), surveys can be used to generate a frequency distribution of numerical values (*e.g.*, the number of households with electricity rates at particular levels) to estimate the probability of each value. For quantities with uncertainty, statistical or subjective measures can be used to provide probabilities (*e.g.*, manufacturing cost to improve energy efficiency to some level may be estimated to be $\$10 \pm \$3$).

The major disadvantage of the probability approach is that it requires more information, namely information about the shapes and magnitudes of the variability and uncertainty of each quantity. The advantage of the probability approach is that it provides greater information about the outcome of the calculations, that is, it provides the probability that the outcome will be in a particular range.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.6 PROBABILITY ANALYSIS AND THE USE OF CRYSTAL BALL

To quantify the uncertainty and variability that exist in inputs to the engineering, LCC, and PBP analyses, the U.S. Department of Energy (DOE) used Microsoft Excel spreadsheets combined with Crystal Ball, a commercially available add-in application, to conduct probability analyses. The probability analyses used Monte Carlo simulation and probability distributions.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a spreadsheet model will only reveal a single outcome, generally the most likely or average scenario. Spreadsheet risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on outputs of the modeled system. One type of spreadsheet simulation is Monte Carlo simulation, which randomly generates values for uncertain variables again and again to simulate a system. Monte Carlo simulation was named for Monte Carlo, Monaco, where the primary attractions are casinos containing games of chance. Games of chance, such as roulette wheels, dice, and slot machines, exhibit random behavior. The random behavior in games of chance is similar to how Monte Carlo simulation utilizes variable values at random to simulate a model. For example, one knows that a rolled die will present a 1, 2, 3, 4, 5, or 6 after coming to rest, but one does not know which value will be presented on any particular roll. It is the same with the variables that have a known range of values but an uncertain value for any particular time or event (*e.g.*, product lifetime, discount rate, and installation cost).

For each uncertain variable, possible values are defined with a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. The different probability distribution types are shown in Figure 8B.6.1 through Figure 8B.6.3:

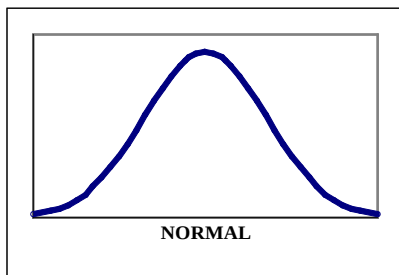


Figure 8B.6.1 Normal Probability Distribution

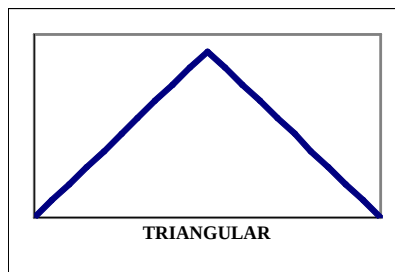


Figure 8B.6.2 Triangular Probability Distribution

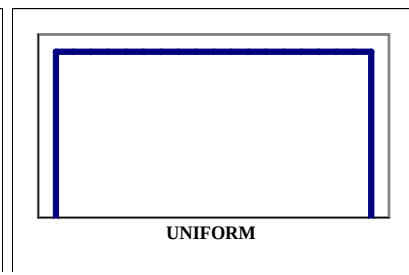


Figure 8B.6.3 Uniform Probability Distribution

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values in the simulation. Crystal Ball simulations can consist of as many trials (or scenarios) as desired—hundreds or even thousands. During a single trial, Crystal Ball randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the spreadsheet.

8B.7 GENERAL SERVICE FLUORESCENT LAMPS RESULTS

DOE analyzed five product classes for GSFLs: 4-foot medium bipin (MBP), 4-foot T5 miniature bipin (MiniBP) standard output (SO), 4-foot T5 MiniBP high output (HO), 8-foot single pin (SP) slimline, and 8-foot recessed double contact (RDC) HO, all with a correlated color temperature (CCT) less than or equal to 4,500 kelvin (K). For each of these representative product classes, DOE conducted both probability analyses (based on Monte Carlo runs) and scenario analyses.

8B.7.1 Monte Carlo Results

To characterize the LCC savings and Monte Carlo results for GSFLs, DOE developed tables to describe the distributions of the results. These tables document the average LCC savings and percentages of buildings analyzed with positive and negative LCC savings for various systems in each event analyzed. In addition, DOE reports the median and average payback period for each system analyzed for each event.

8B.7.1.1 Product Class: 4-foot medium bipin $\leq$ 4,500 K

The following tables present the LCC savings and PBP results based on Monte Carlo runs for the 4-foot MBP lamps with CCT less than or equal to 4,500 K. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.1 LCC and PBP Monte Carlo Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	117.80	135.16	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	32.83	117.80	138.83	-3.66	100	0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.79	98.70	128.67	6.49	0.1	99.9	3.3	3.5
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.73	117.80	144.71	-9.55	100	0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	23.99	105.87	130.04	5.13	0	100	2.9	3.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	59.99	116.30	159.40	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	75.63	104.01	150.78	8.62	0	100	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.59	97.39	153.10	6.30	0.1	99.9	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.53	101.78	154.43	4.97	0.1	99.9	3.3	3.5
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.79	102.68	152.59	6.81	0	100	2.5	2.7
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.78	116.30	161.09	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.43	104.01	152.46	8.62	0	100	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.39	97.39	154.78	6.30	0.1	99.9	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.33	101.78	156.12	4.97	0.1	99.9	3.3	3.5
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.58	102.68	154.27	6.81	0	100	2.5	2.7

Table 8B.7.2 LCC and PBP Monte Carlo Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.20	84.26	101.63	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	32.75	84.26	105.35	-3.72	100	0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.81	70.60	100.59	1.04	44.2	55.8	4.0	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.75	84.26	111.19	-9.56	100	0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	24.00	75.73	99.91	1.73	9	91	3.5	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	60.01	83.19	126.56	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	75.56	74.40	121.49	5.07	0	100	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.63	69.66	125.65	0.91	45	55	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.56	72.80	125.73	0.83	43.3	56.7	4.0	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.82	73.45	123.63	2.93	0	100	3.1	3.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.80	83.19	128.26	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.36	74.40	123.19	5.07	0	100	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.42	69.66	127.35	0.91	45	55	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.36	72.80	127.43	0.83	43.3	56.7	4.0	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.61	73.45	125.33	2.93	0	100	3.1	3.0

Table 8B.7.3 LCC and PBP Monte Carlo Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	180.70	198.03	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	31.48	180.70	204.53	-6.49	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.79	151.71	181.65	16.38	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.73	180.70	207.58	-9.55	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	23.99	162.60	186.73	11.30	0.0	100.0	2.9	3.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.19	180.70	236.05	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.48	180.70	242.54	-6.49	100.0	0.0	NER	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.48	151.93	213.77	22.28	0.0	100.0	0.3	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.79	151.71	219.66	16.38	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.73	180.70	245.59	-9.55	100.0	0.0	NER	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.73	151.93	216.83	19.22	0.0	100.0	2.6	2.7
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	67.99	162.60	224.74	11.30	0.0	100.0	2.9	3.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.98	180.70	238.46	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	78.27	180.70	244.95	-6.49	100.0	0.0	NER	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	78.27	151.93	216.18	22.28	0.0	100.0	0.3	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.59	151.71	222.08	16.38	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.53	180.70	248.01	-9.55	100.0	0.0	NER	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.53	151.93	219.24	19.22	0.0	100.0	2.6	2.7
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.78	162.60	227.16	11.30	0.0	100.0	2.9	3.1

Table 8B.7.4 LCC and PBP Monte Carlo Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.20	128.80	146.14	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	31.10	128.80	152.36	-6.21	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.81	108.14	138.10	8.05	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.75	128.80	155.70	-9.56	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	24.00	115.90	140.05	6.10	0.0	100.0	3.5	3.5
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.21	128.80	184.26	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.12	128.80	190.48	-6.21	100.0	0.0	NER	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.12	108.30	169.97	14.29	0.0	100.0	0.4	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.83	108.14	176.22	8.05	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.77	128.80	193.82	-9.56	100.0	0.0	NER	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.77	108.30	173.32	10.95	0.0	100.0	3.1	3.1
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	68.02	115.90	178.17	6.10	0.0	100.0	3.5	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	64.01	128.80	186.69	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	77.91	128.80	192.90	-6.21	100.0	0.0	NER	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	77.91	108.30	172.39	14.29	0.0	100.0	0.4	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.63	108.14	178.64	8.05	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.56	128.80	196.24	-9.56	100.0	0.0	NER	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.56	108.30	175.74	10.95	0.0	100.0	3.1	3.1
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.81	115.90	180.59	6.10	0.0	100.0	3.5	3.5

Table 8B.7.5 LCC and PBP Monte Carlo Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.95	227.41	255.71	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	54.15	227.41	262.08	-6.37	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.17	190.34	243.86	11.85	0.2	99.8	3.5	3.6
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	47.05	227.41	274.81	-19.09	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.56	204.25	246.16	9.55	0.0	100.0	3.0	3.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.30	225.54	288.94	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.49	203.90	273.67	15.27	0.0	100.0	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.51	188.71	277.33	11.61	0.3	99.7	3.5	3.7
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.39	197.21	279.70	9.23	0.2	99.8	3.4	3.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.90	202.53	279.53	9.40	0.0	100.0	3.0	3.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.09	225.54	290.62	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	115.29	203.90	275.35	15.27	0.0	100.0	0.5	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.31	188.71	279.01	11.61	0.3	99.7	3.5	3.7
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.19	197.21	281.39	9.23	0.2	99.8	3.4	3.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.70	202.53	281.21	9.40	0.0	100.0	3.0	3.2

Table 8B.7.6 LCC and PBP Monte Carlo Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.97	162.67	190.99	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	54.03	162.67	197.45	-6.47	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.21	136.15	189.71	1.27	47.4	52.6	4.2	4.1
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	47.08	162.67	210.10	-19.11	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.59	146.10	188.04	2.95	16.0	84.0	3.6	3.5
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.33	161.33	225.09	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.39	145.85	216.08	9.01	0.0	100.0	0.6	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.57	134.99	223.99	1.11	48.2	51.8	4.2	4.1
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.45	141.07	223.94	1.15	46.2	53.8	4.1	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.95	144.87	222.25	2.84	17.7	82.3	3.6	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.13	161.33	226.79	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	115.19	145.85	217.78	9.01	0.0	100.0	0.6	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.37	134.99	225.69	1.11	48.2	51.8	4.2	4.1
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.24	141.07	225.64	1.15	46.2	53.8	4.1	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.74	144.87	223.95	2.84	17.7	82.3	3.6	3.5

Table 8B.7.7 LCC and PBP Monte Carlo Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.95	358.50	386.75	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.90	358.50	397.80	-11.05	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.17	300.62	354.09	32.67	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.05	358.50	405.85	-19.09	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.56	322.35	364.20	22.55	0.0	100.0	2.9	3.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.14	358.50	438.75	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	112.08	342.54	433.84	4.91	0.4	99.6	1.1	1.1
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.35	300.62	406.08	32.67	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.23	342.54	441.88	-3.13	81.9	18.1	9.3	9.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.74	307.73	401.57	37.18	0.0	100.0	2.1	2.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.94	358.50	441.16	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.88	342.54	436.25	4.91	0.4	99.6	1.1	1.1
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.15	300.62	408.50	32.67	0.0	100.0	3.4	3.6
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.03	342.54	444.30	-3.13	81.9	18.1	9.3	9.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.54	307.73	403.99	37.18	0.0	100.0	2.1	2.2

Table 8B.7.8 LCC and PBP Monte Carlo Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.97	255.54	283.81	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.29	255.54	294.40	-10.59	100.0	0.0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.21	214.28	267.78	16.02	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.08	255.54	302.92	-19.11	100.0	0.0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.59	229.77	271.65	12.16	0.0	100.0	3.5	3.5
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.18	255.54	335.95	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.49	244.16	335.17	0.78	44.0	56.0	1.3	1.3
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.42	214.28	319.93	16.02	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.29	244.16	343.68	-7.73	99.4	0.6	11.2	11.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.79	219.35	313.37	22.58	0.0	100.0	2.5	2.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.97	255.54	338.37	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.29	244.16	337.59	0.78	44.0	56.0	1.3	1.3
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.21	214.28	322.35	16.02	0.0	100.0	4.1	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.09	244.16	346.10	-7.73	99.4	0.6	11.2	11.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.59	219.35	315.79	22.58	0.0	100.0	2.5	2.5

The following tables present the LCC savings and PBP results based on Monte Carlo runs for 4-foot MBP lamps with CCT less than or equal to 4,500 K in the residential sector. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices. DOE assumed that the analysis period is limited by the ballast lifetime. See chapter 8 of this notice of proposed rulemaking (NOPR) technical support document (TSD) for further details on residential sector GSFL consumer behavior.

Table 8B.7.9 LCC and PBP Monte Carlo Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	10.49	48.03	58.52	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	11.58	48.03	59.61	-1.09	100	0	NER	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	23.09	40.28	63.38	-4.86	94.8	5.2	18.1	18.7
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	20.03	48.03	68.07	-9.55	100	0	NER	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	17.29	43.19	60.48	-1.96	89.8	10.2	15.7	16.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	52.72	48.03	100.75	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	53.81	45.60	99.41	1.34	1.1	98.9	5.0	5.2
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	65.32	40.28	105.61	-4.86	94.8	5.2	18.1	18.7
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	62.26	45.60	107.86	-7.11	100	0	43.7	45.1
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	59.52	41.00	100.52	0.23	49	51	10.8	11.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.51	48.03	103.54	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.60	45.60	102.20	1.34	1.1	98.9	5.0	5.2
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	68.12	40.28	108.40	-4.86	94.8	5.2	18.1	18.7
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	65.06	45.60	110.66	-7.11	100	0	43.7	45.1
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	62.31	41.00	103.31	0.23	49	51	10.8	11.1

8B.7.1.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the Monte Carlo runs for the 4-foot T5 MiniBP HO lamps with CCT less than or equal to 4,500 K. Key inputs consist of using *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.10 LCC and PBP Monte Carlo Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.57	254.28	273.02	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.59	254.28	281.04	-8.02	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.51	232.21	257.80	15.23	0.0	100.0	3.3	3.5
		EL 1	102.1	47 W T5 & 1 BF Prog	35.42	223.01	254.10	18.93	0.0	100.0	2.8	3.0
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.68	254.28	306.37	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.70	254.28	314.39	-8.02	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.61	232.21	291.14	15.23	0.0	100.0	3.3	3.5
		EL 1	102.1	47 W T5 & 1 BF Prog	89.53	223.01	287.44	18.93	0.0	100.0	2.8	3.0
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.47	254.28	308.09	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.49	254.28	316.11	-8.02	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.41	232.21	292.87	15.23	0.0	100.0	3.3	3.5
		EL 1	102.1	47 W T5 & 1 BF Prog	92.32	223.01	289.16	18.93	0.0	100.0	2.8	3.0

Table 8B.7.11 LCC and PBP Monte Carlo Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.58	181.61	200.36	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.61	181.61	208.39	-8.03	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.53	165.85	191.55	8.81	0.0	100.0	4.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	35.44	159.27	190.45	9.91	0.0	100.0	3.4	3.3
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.71	181.61	234.02	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.74	181.61	242.05	-8.03	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.66	165.85	225.21	8.81	0.0	100.0	4.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	89.58	159.27	224.11	9.91	0.0	100.0	3.4	3.3
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.51	181.61	235.76	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.53	181.61	243.79	-8.03	100.0	0.0	NER	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.46	165.85	226.95	8.81	0.0	100.0	4.0	3.9
		EL 1	102.1	47 W T5 & 1 BF Prog	92.37	159.27	225.85	9.91	0.0	100.0	3.4	3.3

8B.7.1.3 Product Class: 4-foot T5 miniature bipin standard output $\leq 4,500$ K

The following tables present LCC savings and PBP results based on Monte Carlo runs for the 4-foot T5 MiniBP SO lamps with CCT less than or equal to 4,500 K. Key inputs consist of using *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.12 LCC and PBP Monte Carlo Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.30	154.07	169.54	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.17	154.07	173.41	-3.87	100.0	0.0	NER	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.52	154.07	175.76	-6.22	100.0	0.0	NER	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.67	144.38	169.22	0.32	57.9	42.1	5.9	6.3
		EL 2	25.0	25 W T5 & 1 BF Prog	27.41	138.99	163.71	5.83	0.2	99.8	4.9	5.2
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.19	154.07	206.77	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.06	135.21	191.78	14.99	0.0	100.0	1.3	1.3
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.41	135.21	194.14	12.64	0.0	100.0	2.0	2.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.56	126.80	188.87	17.90	0.0	100.0	2.1	2.2
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.30	122.12	184.07	22.70	0.0	100.0	2.3	2.5
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	70.99	154.07	208.74	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.85	135.21	193.75	14.99	0.0	100.0	1.3	1.3
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.21	135.21	196.11	12.64	0.0	100.0	2.0	2.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.35	126.80	190.84	17.90	0.0	100.0	2.1	2.2
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.10	122.12	186.04	22.70	0.0	100.0	2.3	2.5

Table 8B.7.13 LCC and PBP Monte Carlo Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.31	109.94	125.41	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.18	109.94	129.28	-3.87	100.0	0.0	NER	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.54	109.94	131.64	-6.23	100.0	0.0	NER	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.68	103.02	127.87	-2.46	95.6	4.4	7.2	7.0
		EL 2	25.0	25 W T5 & 1 BF Prog	27.43	99.18	123.99	1.42	28.8	71.2	5.9	5.8
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.22	109.94	163.10	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.09	96.48	153.52	9.59	0.0	100.0	1.5	1.5
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.45	96.48	155.87	7.23	0.0	100.0	2.4	2.4
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.60	90.48	153.02	10.08	0.0	100.0	2.5	2.5
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.34	87.14	149.64	13.46	0.0	100.0	2.8	2.8
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	71.02	109.94	165.09	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.89	96.48	155.51	9.59	0.0	100.0	1.5	1.5
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.24	96.48	157.87	7.23	0.0	100.0	2.4	2.4
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.39	90.48	155.01	10.08	0.0	100.0	2.5	2.5
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.14	87.14	151.63	13.46	0.0	100.0	2.8	2.8

8B.7.1.4 Product Class: 8-foot single pin slimline $\leq 4,500$ K

The following tables present the LCC savings and PBP results based on Monte Carlo runs for the 8-foot SP slimline lamps with CCT less than or equal to 4,500 K. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.14 LCC and PBP Monte Carlo Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.72	221.06	248.15	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.40	221.06	250.83	-2.68	100.0	0.0	NER	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.52	221.06	255.95	-7.80	100.0	0.0	NER	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.51	209.62	253.50	-5.35	96.1	3.9	7.3	7.7
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.86	194.37	245.60	2.55	44.6	55.4	4.5	4.8
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.46	217.67	289.68	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.13	194.37	269.06	20.62	0.0	100.0	0.6	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.25	194.37	274.17	15.50	0.0	100.0	1.7	1.8
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.24	184.30	273.09	16.58	0.0	100.0	2.5	2.6
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.60	191.30	287.45	2.23	47.6	52.4	4.6	4.8
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.25	217.67	291.34	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.93	194.37	270.71	20.62	0.0	100.0	0.6	0.6
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.05	194.37	275.83	15.50	0.0	100.0	1.7	1.8
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.04	184.30	274.75	16.58	0.0	100.0	2.5	2.6
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.39	191.30	289.11	2.23	47.6	52.4	4.6	4.8

Table 8B.7.15 LCC and PBP Monte Carlo Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.74	158.15	185.26	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.42	158.15	187.94	-2.68	100.0	0.0	NER	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.54	158.15	193.06	-7.80	100.0	0.0	NER	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.54	149.97	193.88	-8.62	100.0	0.0	8.8	8.7
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.90	139.06	190.33	-5.07	93.3	6.7	5.4	5.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.49	155.73	228.35	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.17	139.06	214.36	13.99	0.0	100.0	0.7	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.30	139.06	219.48	8.87	0.0	100.0	2.0	2.0
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.29	131.86	221.27	7.07	0.0	100.0	3.0	3.0
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.65	136.86	233.64	-5.29	93.8	6.2	5.5	5.4
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.29	155.73	230.03	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.97	139.06	216.03	13.99	0.0	100.0	0.7	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.09	139.06	221.16	8.87	0.0	100.0	2.0	2.0
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.09	131.86	222.95	7.07	0.0	100.0	3.0	3.0
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.45	136.86	235.32	-5.29	93.8	6.2	5.5	5.4

8B.7.1.5 Product Class: 8-foot recessed double contact high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results based on Monte Carlo runs for the 8-foot RDC HO lamps with CCT less than or equal to 4,500 K. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.16 LCC and PBP Monte Carlo Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.44	239.82	264.67	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.00	239.82	274.23	-9.56	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.21	239.82	281.43	-16.76	100.0	0.0	NER	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.33	239.82	299.78	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.89	239.82	309.34	-9.56	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.09	239.82	316.54	-16.76	100.0	0.0	NER	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.12	239.82	301.07	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.68	239.82	310.63	-9.56	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.89	239.82	317.84	-16.76	100.0	0.0	NER	NER

Table 8B.7.17 LCC and PBP Monte Carlo Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.46	171.88	196.73	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.03	171.88	206.30	-9.57	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.24	171.88	213.51	-16.78	100.0	0.0	NER	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.36	171.88	233.78	N/A	N/A	N/A	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.92	171.88	243.35	-9.57	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.14	171.88	250.56	-16.78	100.0	0.0	NER	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.15	171.88	235.15	N/A	N/A	N/A	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.72	171.88	244.71	-9.57	100.0	0.0	NER	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.93	171.88	251.92	-16.78	100.0	0.0	NER	NER

8B.7.2 Lamp Price Scenario Results

As mentioned earlier, DOE also analyzed LCC savings and PBP results using a scenario analysis. Because the LCC and PBP results are highly dependent on product prices, DOE examined sensitivities to the average-weighted lamp price results presented in chapter 8 of this TSD by considering the low and high prices developed for GSFLs in chapter 7 of this TSD. The following tables present LCC savings and PBP results using the high and low lamp prices.

8B.7.2.1 Product Class: 4-foot medium bipin $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K, considering high or low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.18 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	22.01	116.96	139.15	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	42.97	116.96	144.88	-5.73	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	40.40	98.00	138.58	0.57	4.7
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	35.92	116.96	153.06	-13.91	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	31.91	105.12	137.21	1.94	4.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	64.81	115.47	163.57	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	85.77	103.28	157.10	6.47	0.6
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	83.20	96.70	163.18	0.38	4.8
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	78.72	101.06	163.06	0.51	4.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	74.71	101.96	159.95	3.61	3.6
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	67.60	115.47	165.26	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	88.57	103.28	158.79	6.47	0.6
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	86.00	96.70	164.88	0.38	4.8
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	81.51	101.06	164.75	0.51	4.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	77.51	101.96	161.64	3.61	3.6

Table 8B.7.19 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	12.85	116.96	129.99	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	24.69	116.96	132.96	-2.97	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	20.19	98.00	118.37	11.62	1.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	18.41	116.96	135.56	-5.57	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	16.80	105.12	122.10	7.89	1.6
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	55.65	115.47	154.41	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	67.49	103.28	145.18	9.23	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	62.99	96.70	142.98	11.43	1.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	61.21	101.06	145.56	8.85	1.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	59.60	101.96	144.84	9.57	1.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	58.44	115.47	156.10	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	70.28	103.28	146.87	9.23	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	65.79	96.70	144.67	11.43	1.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	64.01	101.06	147.25	8.85	1.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	62.39	101.96	146.53	9.57	1.4

Table 8B.7.20 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	22.01	84.04	106.23	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	42.09	84.04	111.23	-5.00	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	40.41	70.42	111.01	-4.77	5.7
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	35.93	84.04	120.15	-13.91	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	31.92	75.53	107.63	-1.40	4.9
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	64.82	82.97	131.26	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	84.90	74.21	127.49	3.76	0.8
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	83.22	69.48	136.17	-4.91	5.8
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	78.73	72.61	134.81	-3.56	5.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	74.73	73.26	131.45	-0.20	4.3
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	67.62	82.97	132.96	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	87.69	74.21	129.20	3.76	0.8
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	86.02	69.48	137.87	-4.91	5.8
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	81.53	72.61	136.52	-3.56	5.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	77.52	73.26	133.15	-0.20	4.3

Table 8B.7.21 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	12.85	84.04	97.07	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	24.18	84.04	99.62	-2.55	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	20.20	70.42	90.79	6.28	2.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	18.42	84.04	102.64	-5.57	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	16.80	75.53	92.51	4.56	2.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	55.66	82.97	122.09	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	66.98	74.21	115.88	6.22	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	63.00	69.48	115.95	6.14	2.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	61.22	72.61	117.30	4.79	2.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	59.61	73.26	116.33	5.76	1.7
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	58.45	82.97	123.80	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	69.78	74.21	117.58	6.22	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	65.80	69.48	117.66	6.14	2.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	64.02	72.61	119.01	4.79	2.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	62.40	73.26	118.04	5.76	1.7

Table 8B.7.22 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	22.01	178.88	201.04	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	40.25	178.88	209.09	-8.04	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	40.40	150.18	190.74	10.30	4.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	35.92	178.88	214.95	-13.91	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	31.91	160.96	193.02	8.02	4.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	66.01	178.88	238.93	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	84.25	178.88	246.97	-8.04	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	84.25	150.40	218.50	20.43	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	84.40	150.18	228.63	10.30	4.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	79.92	178.88	252.84	-13.91	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	79.92	150.40	224.36	14.57	3.6
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	75.91	160.96	230.91	8.02	4.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	68.80	178.88	241.34	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	87.04	178.88	249.38	-8.04	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	87.04	150.40	220.90	20.43	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	87.20	150.18	231.03	10.30	4.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	82.71	178.88	255.25	-13.91	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	82.71	150.40	226.77	14.57	3.6
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	78.71	160.96	233.32	8.02	4.1

Table 8B.7.23 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	12.85	178.88	191.88	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	23.14	178.88	196.22	-4.34	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	20.19	150.18	170.53	21.35	1.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	18.41	178.88	197.45	-5.57	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	16.80	160.96	177.91	13.97	1.6
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	56.85	178.88	229.77	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	67.14	178.88	234.11	-4.34	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	67.14	150.40	205.63	24.14	0.2
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	64.19	150.18	208.42	21.35	1.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	62.41	178.88	235.33	-5.57	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	62.41	150.40	206.86	22.91	1.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	60.80	160.96	215.80	13.97	1.6
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	59.64	178.88	232.18	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	69.93	178.88	236.51	-4.34	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	69.93	150.40	208.04	24.14	0.2
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	66.99	150.18	210.83	21.35	1.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	65.21	178.88	237.74	-5.57	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	65.21	150.40	209.26	22.91	1.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	63.60	160.96	218.21	13.97	1.6

Table 8B.7.24 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	22.01	128.12	150.28	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	39.90	128.12	158.44	-8.16	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	40.41	107.56	148.12	2.15	5.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	35.93	128.12	164.19	-13.91	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	31.92	115.28	147.35	2.93	5.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	66.02	128.12	188.46	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	83.91	128.12	196.62	-8.16	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	83.91	107.72	176.23	12.24	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	84.42	107.56	186.31	2.15	5.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	79.93	128.12	202.38	-13.91	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	79.93	107.72	181.98	6.48	4.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	75.93	115.28	185.53	2.93	5.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	68.82	128.12	190.89	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	86.70	128.12	199.05	-8.16	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	86.70	107.72	178.65	12.24	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	87.22	107.56	188.74	2.15	5.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	82.73	128.12	204.80	-13.91	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	82.73	107.72	184.41	6.48	4.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	78.72	115.28	187.96	2.93	5.0

Table 8B.7.25 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	12.85	128.12	141.11	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	22.93	128.12	145.52	-4.40	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	20.20	107.56	127.91	13.20	2.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	18.42	128.12	146.68	-5.57	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	16.80	115.28	132.23	8.88	2.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	56.86	128.12	179.30	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	66.93	128.12	183.70	-4.40	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	66.93	107.72	163.31	15.99	0.2
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	64.21	107.56	166.10	13.20	2.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	62.42	128.12	184.87	-5.57	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	62.42	107.72	164.47	14.83	1.8
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	60.81	115.28	170.42	8.88	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	59.65	128.12	181.73	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	69.73	128.12	186.13	-4.40	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	69.73	107.72	165.73	15.99	0.2
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	67.00	107.56	168.52	13.20	2.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	65.22	128.12	187.29	-5.57	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	65.22	107.72	166.90	14.83	1.8
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	63.61	115.28	172.84	8.88	2.0

Table 8B.7.26 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	37.60	225.79	263.75	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	74.25	225.79	274.03	-10.28	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	74.38	188.99	263.73	0.01	4.8
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	65.41	225.79	291.56	-27.82	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	57.41	202.80	260.57	3.18	4.2
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	95.94	223.94	297.21	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	132.60	202.45	286.01	11.20	0.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	132.73	187.37	297.43	-0.22	4.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	123.76	195.81	296.90	0.31	4.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	115.75	201.09	294.17	3.04	4.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	98.74	223.94	298.90	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	135.39	202.45	287.70	11.20	0.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	135.52	187.37	299.12	-0.22	4.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	126.55	195.81	298.59	0.31	4.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	118.54	201.09	295.86	3.04	4.2

Table 8B.7.27 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	19.28	225.79	245.43	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	37.68	225.79	250.19	-4.76	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	33.97	188.99	223.32	22.11	1.9
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	30.41	225.79	256.56	-11.13	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	27.18	202.80	230.34	15.09	1.7
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	77.62	223.94	278.89	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	96.03	202.45	262.16	16.72	0.3
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	92.31	187.37	257.01	21.87	1.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	88.75	195.81	261.89	17.00	1.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	85.52	201.09	263.94	14.94	1.7
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	80.42	223.94	280.58	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	98.82	202.45	263.86	16.72	0.3
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	95.11	187.37	258.71	21.87	1.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	91.55	195.81	263.58	17.00	1.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	88.32	201.09	265.64	14.94	1.7

Table 8B.7.28 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	37.61	162.24	200.20	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	72.73	162.24	209.23	-9.03	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	74.41	135.80	210.56	-10.36	5.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	65.44	162.24	228.03	-27.83	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	57.42	145.72	203.50	-3.30	5.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	95.96	160.90	234.44	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	131.08	145.47	228.03	6.41	0.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	132.76	134.63	244.97	-10.53	5.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	123.79	140.69	242.05	-7.62	5.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	115.78	144.49	237.84	-3.40	5.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	98.76	160.90	236.14	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	133.87	145.47	229.73	6.41	0.9
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	135.56	134.63	246.67	-10.53	5.9
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	126.58	140.69	243.76	-7.62	5.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	118.57	144.49	239.54	-3.40	5.1

Table 8B.7.29 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	19.28	162.24	181.87	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	36.90	162.24	185.99	-4.12	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	33.98	135.80	170.13	11.74	2.4
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	30.42	162.24	193.01	-11.13	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	27.19	145.72	173.26	8.61	2.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	77.63	160.90	216.11	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	95.25	145.47	204.80	11.32	0.3
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	92.33	134.63	204.54	11.57	2.4
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	88.77	140.69	207.04	9.08	2.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	85.54	144.49	207.60	8.51	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	80.43	160.90	217.82	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	98.05	145.47	206.50	11.32	0.3
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	95.13	134.63	206.24	11.57	2.4
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	91.56	140.69	208.74	9.08	2.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	88.33	144.49	209.31	8.51	2.0

Table 8B.7.30 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	37.60	354.89	392.80	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	69.51	354.89	407.09	-14.29	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	74.38	297.59	372.28	20.51	4.8
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	65.41	354.89	420.61	-27.82	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	57.41	319.10	376.82	15.98	4.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	97.78	354.89	444.62	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	129.70	339.09	443.11	1.51	1.5
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	134.57	297.59	424.11	20.51	4.8
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	125.60	339.09	456.64	-12.01	13.1
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	117.59	304.62	414.16	30.46	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	100.58	354.89	447.03	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	132.49	339.09	445.52	1.51	1.5
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	137.37	297.59	426.52	20.51	4.8
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	128.40	339.09	459.05	-12.01	13.1
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	120.39	304.62	416.57	30.46	2.9

Table 8B.7.31 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	19.28	354.89	374.48	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	35.29	354.89	381.35	-6.87	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	33.97	297.59	331.87	42.61	1.9
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	30.41	354.89	385.61	-11.13	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	27.18	319.10	346.59	27.89	1.6
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	79.46	354.89	426.30	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	95.48	339.09	417.38	8.93	0.6
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	94.16	297.59	383.70	42.61	1.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	90.59	339.09	421.63	4.67	5.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	87.37	304.62	383.94	42.37	1.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	82.26	354.89	428.71	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	98.27	339.09	419.78	8.93	0.6
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	96.95	297.59	386.10	42.61	1.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	93.39	339.09	424.04	4.67	5.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	90.16	304.62	386.35	42.37	1.2

Table 8B.7.32 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	37.61	254.18	292.08	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	68.93	254.18	306.57	-14.49	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	74.41	213.14	287.84	4.24	5.8
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	65.44	254.18	319.91	-27.83	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	57.42	228.54	286.26	5.82	5.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	97.80	254.18	344.32	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	129.12	242.86	347.49	-3.18	1.8
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	134.60	213.14	340.08	4.24	5.8
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	125.63	242.86	360.82	-16.51	15.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	117.62	218.18	328.13	16.19	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	100.60	254.18	346.74	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	131.92	242.86	349.92	-3.18	1.8
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	137.40	213.14	342.50	4.24	5.8
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	128.43	242.86	363.25	-16.51	15.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	120.42	218.18	330.55	16.19	3.5

Table 8B.7.33 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	19.28	254.18	273.76	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	34.98	254.18	280.73	-6.98	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	33.98	213.14	247.41	26.34	2.3
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	30.42	254.18	284.89	-11.13	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	27.19	228.54	256.03	17.73	2.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	79.48	254.18	325.99	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	95.17	242.86	321.65	4.34	0.7
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	94.18	213.14	299.65	26.34	2.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	90.61	242.86	325.81	0.18	6.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	87.38	218.18	297.89	28.10	1.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	82.27	254.18	328.41	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	97.97	242.86	324.08	4.34	0.7
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	96.97	213.14	302.07	26.34	2.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	93.41	242.86	328.23	0.18	6.3
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	90.18	218.18	300.32	28.10	1.4

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K operating in the residential sector with high and low lamp prices. Key inputs consist of using the *AEO 2013* reference case electricity prices. Residential average operating hours were used with an analysis period of 15 years.

Table 8B.7.34 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	15.30	46.85	62.16	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	16.88	46.85	63.73	-1.57	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	33.70	39.29	72.99	-10.83	25.7
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	29.21	46.85	76.06	-13.91	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	25.21	42.13	67.34	-5.18	22.2
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	57.53	46.85	104.38	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	59.11	44.48	103.58	0.80	7.0
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	75.92	39.29	115.21	-10.83	25.7
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	71.44	44.48	115.91	-11.53	61.8
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	67.43	39.99	107.42	-3.04	15.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	60.33	46.85	107.18	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	61.90	44.48	106.38	0.80	7.0
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	78.72	39.29	118.01	-10.83	25.7
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	74.23	44.48	118.71	-11.53	61.8
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	70.23	39.99	110.22	-3.04	15.2

Table 8B.7.35 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	6.15	46.85	53.00	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	6.78	46.85	53.63	-0.63	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	13.49	39.29	52.78	0.22	10.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	11.71	46.85	58.56	-5.56	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	10.10	42.13	52.23	0.77	8.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	48.37	46.85	95.22	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	49.00	44.48	93.48	1.74	2.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	55.72	39.29	95.01	0.22	10.3
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	53.94	44.48	98.41	-3.19	24.7
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	52.32	39.99	92.31	2.91	6.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	51.17	46.85	98.02	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	51.80	44.48	96.28	1.74	2.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	58.51	39.29	97.80	0.22	10.3
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	56.73	44.48	101.21	-3.19	24.7
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	55.12	39.99	95.11	2.91	6.1

8B.7.2.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the 4-foot MiniBP HO lamps with CCT less than or equal to 4,500 K with high and low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.36 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	24.02	252.42	276.62	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	35.73	252.42	288.33	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	44.35	230.52	265.49	11.13	4.7
		EL 1	102.1	47 W T5 & 1 BF Prog	48.61	221.38	264.06	12.56	4.0
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	78.13	252.42	310.17	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	89.84	252.42	321.87	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	98.46	230.52	299.04	11.13	4.7
		EL 1	102.1	47 W T5 & 1 BF Prog	102.71	221.38	297.60	12.56	4.0
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	80.92	252.42	311.90	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	92.63	252.42	323.61	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	101.25	230.52	300.77	11.13	4.7
		EL 1	102.1	47 W T5 & 1 BF Prog	105.51	221.38	299.34	12.56	4.0

Table 8B.7.37 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	13.62	252.42	266.23	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	18.33	252.42	270.93	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	21.77	230.52	247.73	18.50	1.9
		EL 1	102.1	47 W T5 & 1 BF Prog	23.47	221.38	242.05	24.17	1.6
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	67.73	252.42	299.77	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	72.44	252.42	304.48	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	75.88	230.52	281.27	18.50	1.9
		EL 1	102.1	47 W T5 & 1 BF Prog	77.58	221.38	275.60	24.17	1.6
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	70.53	252.42	301.50	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	75.23	252.42	306.21	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	78.68	230.52	283.00	18.50	1.9
		EL 1	102.1	47 W T5 & 1 BF Prog	80.38	221.38	277.33	24.17	1.6

Table 8B.7.38 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	24.03	181.10	205.30	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	35.74	181.10	217.01	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	44.36	165.38	200.47	4.83	5.7
		EL 1	102.1	47 W T5 & 1 BF Prog	48.62	158.83	201.59	3.72	4.8
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	78.15	181.10	239.08	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	89.86	181.10	250.79	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	98.48	165.38	234.24	4.83	5.7
		EL 1	102.1	47 W T5 & 1 BF Prog	102.74	158.83	235.36	3.72	4.8
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	80.94	181.10	240.82	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	92.65	181.10	252.53	-11.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	101.28	165.38	235.99	4.83	5.7
		EL 1	102.1	47 W T5 & 1 BF Prog	105.54	158.83	237.11	3.72	4.8

Table 8B.7.39 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	13.63	181.10	194.90	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	18.33	181.10	199.61	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	21.78	165.38	182.65	12.25	2.3
		EL 1	102.1	47 W T5 & 1 BF Prog	23.48	158.83	179.54	15.36	1.9
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	67.75	181.10	228.68	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	72.45	181.10	233.38	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	75.90	165.38	216.42	12.25	2.3
		EL 1	102.1	47 W T5 & 1 BF Prog	77.60	158.83	213.31	15.36	1.9
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	70.54	181.10	230.42	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	75.25	181.10	235.13	-4.71	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	78.70	165.38	218.17	12.25	2.3
		EL 1	102.1	47 W T5 & 1 BF Prog	80.39	158.83	215.06	15.36	1.9

8B.7.2.3 Product Class: 4-foot T5 miniature bipin standard output $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 4-foot T5 MiniBP HO lamps with CCT less than or equal to 4,500 K with high and low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.40 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	19.26	152.84	172.28	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	24.89	152.84	177.90	-5.63	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	28.34	152.84	181.35	-9.07	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	32.93	143.23	176.33	-4.05	8.3
		EL 2	25.0	25 W T5 & 1 BF Prog	36.93	137.88	171.19	1.09	6.9
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	72.15	152.84	209.70	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	77.78	134.13	196.62	13.08	1.8
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	81.23	134.13	200.06	9.64	2.8
		EL 2	26.0	26 W T5 & 0.85 BF Prog	85.82	125.79	196.31	13.39	3.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	89.82	121.15	191.87	17.83	3.3
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	74.95	152.84	211.68	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	80.58	134.13	198.60	13.08	1.8
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	84.02	134.13	202.04	9.64	2.8
		EL 2	26.0	26 W T5 & 0.85 BF Prog	88.61	125.79	198.29	13.39	3.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	92.62	121.15	193.85	17.83	3.3

Table 8B.7.41 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	11.74	152.84	164.75	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	13.99	152.84	167.00	-2.25	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	15.36	152.84	168.37	-3.62	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	17.20	143.23	160.61	4.14	3.3
		EL 2	25.0	25 W T5 & 1 BF Prog	18.80	137.88	154.90	9.85	2.8
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	64.63	152.84	202.17	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	66.88	134.13	185.72	16.45	0.7
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	68.25	134.13	187.09	15.09	1.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	70.10	125.79	180.59	21.58	1.2
		EL 2	25.0	25 W T5 & 0.85 BF Prog	71.69	121.15	175.58	26.59	1.3
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	67.42	152.84	204.15	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	69.68	134.13	187.70	16.45	0.7
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	71.05	134.13	189.07	15.09	1.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	72.89	125.79	182.57	21.58	1.2
		EL 2	25.0	25 W T5 & 0.85 BF Prog	74.49	121.15	177.56	26.59	1.3

Table 8B.7.42 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	19.27	109.55	128.98	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	24.90	109.55	134.61	-5.63	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	28.34	109.55	138.06	-9.08	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	32.94	102.66	135.76	-6.78	10.1
		EL 2	25.0	25 W T5 & 1 BF Prog	36.94	98.83	132.22	-3.24	8.4
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	72.17	109.55	166.77	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	77.80	96.14	158.99	7.78	2.1
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	81.25	96.14	162.44	4.33	3.5
		EL 2	26.0	26 W T5 & 0.85 BF Prog	85.84	90.16	161.05	5.72	3.6
		EL 2	25.0	25 W T5 & 0.85 BF Prog	89.84	86.83	158.02	8.75	4.0
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	74.96	109.55	168.77	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	80.60	96.14	160.99	7.78	2.1
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	84.04	96.14	164.44	4.33	3.5
		EL 2	26.0	26 W T5 & 0.85 BF Prog	88.63	90.16	163.05	5.72	3.6
		EL 2	25.0	25 W T5 & 0.85 BF Prog	92.64	86.83	160.01	8.75	4.0

Table 8B.7.43 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	11.74	109.55	121.45	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	13.99	109.55	123.71	-2.26	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	15.36	109.55	125.08	-3.62	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	17.21	102.66	120.03	1.42	4.1
		EL 2	25.0	25 W T5 & 1 BF Prog	18.80	98.83	115.88	5.57	3.4
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	64.64	109.55	159.24	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	66.90	96.14	148.09	11.15	0.9
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	68.27	96.14	149.46	9.78	1.4
		EL 2	26.0	26 W T5 & 0.85 BF Prog	70.11	90.16	145.32	13.92	1.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	71.70	86.83	141.68	17.57	1.6
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	67.44	109.55	161.24	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	69.69	96.14	150.09	11.15	0.9
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	71.06	96.14	151.46	9.78	1.4
		EL 2	26.0	26 W T5 & 0.85 BF Prog	72.91	90.16	147.32	13.92	1.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	74.50	86.83	143.67	17.57	1.6

8B.7.2.4 Product Class: 8-foot single pin slimline $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 8-foot SP slimline lamps with CCT less than or equal to 4,500 K, considering high or low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.44 LCC and PBP Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	36.83	219.51	256.69	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	40.72	219.51	260.59	-3.89	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	48.19	219.51	268.05	-11.36	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	61.28	208.16	269.80	-13.10	10.3
		EL 2	108.0	50 W T8 & 0.87 BF Inst	72.06	193.01	265.42	-8.73	6.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	112.56	216.15	298.67	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	116.45	193.01	279.43	19.24	0.8
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	123.92	193.01	286.90	11.78	2.3
		EL 2	105.6	54 W T8 & 0.77 BF Inst	137.02	183.01	290.00	8.68	3.5
		EL 2	108.0	50 W T8 & 0.87 BF Inst	147.79	189.96	307.72	-9.04	6.4
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	115.36	216.15	300.35	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	119.25	193.01	281.10	19.24	0.8
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	126.72	193.01	288.57	11.78	2.3
		EL 2	105.6	54 W T8 & 0.77 BF Inst	139.81	183.01	291.67	8.68	3.5
		EL 2	108.0	50 W T8 & 0.87 BF Inst	150.59	189.96	309.39	-9.04	6.4

Table 8B.7.45 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	17.58	219.51	237.45	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	19.15	219.51	239.02	-1.57	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	22.15	219.51	242.02	-4.57	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	27.41	208.16	235.92	1.53	4.1
		EL 2	108.0	50 W T8 & 0.87 BF Inst	31.71	193.01	225.07	12.38	2.5
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	93.32	216.15	279.43	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	94.89	193.01	257.86	21.57	0.3
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	97.89	193.01	260.86	18.57	0.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	103.14	183.01	256.12	23.31	1.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	107.44	189.96	267.37	12.07	2.6
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	96.12	216.15	281.11	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	97.68	193.01	259.53	21.57	0.3
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	100.68	193.01	262.54	18.57	0.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	105.94	183.01	257.80	23.31	1.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	110.24	189.96	269.04	12.07	2.6

Table 8B.7.46 LCC and PBP Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	36.84	157.75	194.94	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	40.73	157.75	198.83	-3.89	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	48.20	157.75	206.30	-11.36	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	61.30	149.59	211.25	-16.31	12.5
		EL 2	108.0	50 W T8 & 0.87 BF Inst	72.08	138.70	211.14	-16.20	7.7
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	112.58	155.33	238.20	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	116.48	138.70	225.47	12.73	1.0
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	123.95	138.70	232.94	5.26	2.8
		EL 2	105.6	54 W T8 & 0.77 BF Inst	137.05	131.52	238.86	-0.65	4.3
		EL 2	108.0	50 W T8 & 0.87 BF Inst	147.83	136.51	254.63	-16.42	7.8
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	115.38	155.33	239.89	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	119.27	138.70	227.16	12.73	1.0
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	126.74	138.70	234.63	5.26	2.8
		EL 2	105.6	54 W T8 & 0.77 BF Inst	139.84	131.52	240.54	-0.65	4.3
		EL 2	108.0	50 W T8 & 0.87 BF Inst	150.62	136.51	256.31	-16.42	7.8

Table 8B.7.47 LCC and PBP Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	17.59	157.75	175.69	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	19.16	157.75	177.26	-1.57	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	22.16	157.75	180.26	-4.57	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	27.42	149.59	177.36	-1.67	5.0
		EL 2	108.0	50 W T8 & 0.87 BF Inst	31.72	138.70	170.77	4.92	3.1
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	93.33	155.33	218.95	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	94.90	138.70	203.89	15.06	0.4
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	97.90	138.70	206.90	12.06	1.1
		EL 2	105.6	54 W T8 & 0.77 BF Inst	103.16	131.52	204.97	13.98	1.7
		EL 2	108.0	50 W T8 & 0.87 BF Inst	107.46	136.51	214.26	4.69	3.1
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	96.13	155.33	220.64	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	97.69	138.70	205.58	15.06	0.4
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	100.70	138.70	208.58	12.06	1.1
		EL 2	105.6	54 W T8 & 0.77 BF Inst	105.96	131.52	206.66	13.98	1.7
		EL 2	108.0	50 W T8 & 0.87 BF Inst	110.25	136.51	215.95	4.69	3.1

8B.7.2.5 Product Class: 8-foot recessed double contact HO $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 8-foot RDC HO lamps with CCT less than or equal to 4,500 K, considering high or low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.48 LCC and PBP Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	32.77	238.37	271.53	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	46.71	238.37	285.47	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	57.20	238.37	295.97	-24.44	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	108.65	238.37	306.86	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	122.59	238.37	320.80	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	133.09	238.37	331.29	-24.44	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	111.45	238.37	308.16	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	125.39	238.37	322.10	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	135.88	238.37	332.60	-24.44	NER

Table 8B.7.49 LCC and PBP Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	16.92	238.37	255.68	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	22.50	238.37	261.26	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	26.72	238.37	265.49	-9.80	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	92.80	238.37	291.01	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	98.38	238.37	296.59	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	102.61	238.37	300.82	-9.80	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	95.60	238.37	292.31	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	101.18	238.37	297.89	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	105.40	238.37	302.12	-9.80	NER

Table 8B.7.50 LCC and PBP Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector with High Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	32.78	171.55	204.71	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	46.72	171.55	218.65	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	57.22	171.55	229.15	-24.44	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	108.67	171.55	241.91	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	122.61	171.55	255.86	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	133.11	171.55	266.36	-24.44	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	111.46	171.55	243.28	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	125.41	171.55	257.23	-13.94	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	135.91	171.55	267.73	-24.44	NER

Table 8B.7.51 LCC and PBP Results for a Two-Lamp 8-foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	16.92	171.55	188.85	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	22.50	171.55	194.43	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	26.73	171.55	198.66	-9.81	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	92.81	171.55	226.06	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	98.39	171.55	231.64	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	102.62	171.55	235.87	-9.81	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	95.61	171.55	227.43	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	101.19	171.55	233.01	-5.58	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	105.42	171.55	237.24	-9.81	NER

8B.7.3 Rare Earth Oxide Price Impact Results

The cost of rare earth oxides has varied significantly recently and might continue to fluctuate. Thus, to analyze the impacts of rare earth oxide prices on future lamp prices, DOE derived volatile rare earth oxide price scenarios using historical phosphor price data (see appendix 11B of this NOPR TSD). The following tables present LCC savings and PBP results using the volatile price scenarios.

8B.7.3.1 Product Class: 4-foot medium bipin $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K, considering volatile rare earth prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.52 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	20.04	116.96	137.18	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	38.97	116.96	142.26	-5.07	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	33.73	98.00	131.91	5.27	3.5
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	30.73	116.96	147.87	-10.69	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	27.98	105.12	133.28	3.90	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.84	115.47	161.60	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	81.78	103.28	154.48	7.12	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	76.54	96.70	156.52	5.08	3.5
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	73.53	101.06	157.87	3.73	3.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	70.79	101.96	156.03	5.57	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	65.64	115.47	163.29	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	84.57	103.28	156.17	7.12	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	79.33	96.70	158.21	5.08	3.5
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	76.33	101.06	159.57	3.73	3.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	73.58	101.96	157.72	5.57	2.9

Table 8B.7.53 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	20.04	84.04	104.26	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	38.17	84.04	108.67	-4.41	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	33.74	70.42	104.34	-0.07	4.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	30.74	84.04	114.96	-10.69	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	27.99	75.53	103.70	0.56	3.9
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.86	82.97	129.29	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	80.98	74.21	124.94	4.35	0.6
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	76.55	69.48	129.50	-0.21	4.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	73.55	72.61	129.63	-0.34	4.4
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	70.80	73.26	127.52	1.77	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	65.65	82.97	130.99	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	83.78	74.21	126.64	4.35	0.6
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	79.35	69.48	131.20	-0.21	4.3
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	76.34	72.61	131.33	-0.34	4.4
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	73.60	73.26	129.23	1.77	3.5

Table 8B.7.54 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	20.04	178.88	199.07	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	36.52	178.88	206.26	-7.19	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	33.73	150.18	184.07	15.00	3.5
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	30.73	178.88	209.76	-10.69	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	27.98	160.96	189.09	9.98	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	64.05	178.88	236.97	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	80.53	178.88	244.16	-7.19	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	80.53	150.40	215.68	21.29	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	77.74	150.18	221.96	15.00	3.5
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	74.74	178.88	247.66	-10.69	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	74.74	150.40	219.18	17.79	2.8
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	71.99	160.96	226.99	9.98	3.3
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	66.84	178.88	239.37	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	83.32	178.88	246.57	-7.19	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	83.32	150.40	218.09	21.29	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	80.54	150.18	224.37	15.00	3.5
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	77.53	178.88	250.06	-10.69	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	77.53	150.40	221.59	17.79	2.8
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	74.78	160.96	229.39	9.98	3.3

Table 8B.7.55 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	20.04	128.12	148.31	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	36.20	128.12	155.60	-7.29	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	33.74	107.56	141.45	6.85	4.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	30.74	128.12	159.00	-10.69	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	27.99	115.28	143.42	4.89	4.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	64.06	128.12	186.50	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	80.21	128.12	193.79	-7.29	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	80.21	107.72	173.40	13.10	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	77.76	107.56	179.64	6.85	4.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	74.75	128.12	197.19	-10.69	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	74.75	107.72	176.80	9.70	3.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	72.00	115.28	181.61	4.89	4.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	66.85	128.12	188.92	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	83.01	128.12	196.22	-7.29	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	83.01	107.72	175.82	13.10	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	80.55	107.56	182.07	6.85	4.3
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	77.55	128.12	199.62	-10.69	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	77.55	107.72	179.22	9.70	3.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	74.80	115.28	184.03	4.89	4.0

Table 8B.7.56 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	33.66	225.79	259.81	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	66.25	225.79	268.78	-8.97	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	61.05	188.99	250.40	9.41	3.6
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	55.04	225.79	281.19	-21.38	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	49.55	202.80	252.71	7.10	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	92.01	223.94	293.27	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	124.60	202.45	280.76	12.51	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	119.40	187.37	284.10	9.18	3.6
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	113.39	195.81	286.53	6.75	3.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	107.90	201.09	286.32	6.96	3.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	94.81	223.94	294.97	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	127.40	202.45	282.45	12.51	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	122.19	187.37	285.79	9.18	3.6
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	116.18	195.81	288.22	6.75	3.7
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	110.69	201.09	288.01	6.96	3.4

Table 8B.7.57 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	33.67	162.24	196.26	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	64.89	162.24	204.11	-7.85	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	61.07	135.80	197.22	-0.96	4.4
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	55.06	162.24	217.65	-21.39	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	49.56	145.72	195.63	0.63	4.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	92.03	160.90	230.50	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	123.24	145.47	222.92	7.59	0.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	119.43	134.63	231.63	-1.13	4.4
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	113.42	140.69	231.68	-1.18	4.5
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	107.92	144.49	229.98	0.52	4.1
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	94.82	160.90	232.21	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	126.04	145.47	224.62	7.59	0.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	122.22	134.63	233.33	-1.13	4.4
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	116.21	140.69	233.39	-1.18	4.5
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	110.72	144.49	231.69	0.52	4.1

Table 8B.7.58 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	33.66	354.89	388.86	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	62.06	354.89	401.44	-12.58	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	61.05	297.59	358.95	29.91	3.5
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	55.04	354.89	410.24	-21.38	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	49.55	319.10	368.96	19.91	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	93.85	354.89	440.69	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	122.25	339.09	437.47	3.22	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	121.24	297.59	410.78	29.91	3.5
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	115.23	339.09	446.27	-5.58	10.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	109.74	304.62	406.31	34.38	2.3
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	96.65	354.89	443.10	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	125.05	339.09	439.88	3.22	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	124.04	297.59	413.19	29.91	3.5
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	118.03	339.09	448.68	-5.58	10.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	112.54	304.62	408.72	34.38	2.3

Table 8B.7.59 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	33.67	254.18	288.14	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	61.52	254.18	300.90	-12.76	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	61.07	213.14	274.50	13.64	4.3
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	55.06	254.18	309.53	-21.39	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	49.56	228.54	278.40	9.74	4.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	93.87	254.18	340.38	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	121.72	242.86	341.83	-1.44	1.5
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	121.27	213.14	326.74	13.64	4.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	115.26	242.86	350.45	-10.07	12.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	109.77	218.18	320.27	20.11	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	96.67	254.18	342.81	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	124.52	242.86	344.25	-1.44	1.5
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	124.07	213.14	329.17	13.64	4.3
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	118.06	242.86	352.88	-10.07	12.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	112.56	218.18	322.70	20.11	2.8

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K operating in the residential sector with volatile rare earth prices. Key inputs consist of using the *AEO 2013* reference case electricity prices. Residential average operating hours were used with an analysis period of 15 years.

Table 8B.7.60 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	13.34	46.85	60.19	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	14.65	46.85	61.50	-1.31	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	27.03	39.29	66.32	-6.13	19.1
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	24.02	46.85	70.88	-10.69	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	21.28	42.13	63.41	-3.22	17.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.57	46.85	102.42	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.88	44.48	101.35	1.06	5.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	69.26	39.29	108.55	-6.13	19.1
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	66.25	44.48	110.73	-8.31	47.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	63.51	39.99	103.50	-1.08	12.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	58.36	46.85	105.21	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	59.67	44.48	104.15	1.06	5.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	72.05	39.29	111.34	-6.13	19.1
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	69.05	44.48	113.53	-8.31	47.5
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	66.30	39.99	106.29	-1.08	12.2

8B.7.3.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the 4-foot T5 MiniBP HO lamps with CCT less than or equal to 4,500 K with volatile rare earth prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.61 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	19.11	252.42	271.71	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	28.37	252.42	280.98	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	35.00	230.52	258.14	13.57	3.6
		EL 1	102.1	47 W T5 & 1 BF Prog	37.92	221.38	254.70	17.00	3.0
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	73.22	252.42	305.26	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	82.49	252.42	314.52	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.12	230.52	291.69	13.57	3.6
		EL 1	102.1	47 W T5 & 1 BF Prog	92.04	221.38	288.25	17.00	3.0
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	76.02	252.42	306.99	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	85.29	252.42	316.26	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	91.92	230.52	293.42	13.57	3.6
		EL 1	102.1	47 W T5 & 1 BF Prog	94.83	221.38	289.99	17.00	3.0

Table 8B.7.62 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	19.11	181.10	200.39	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	28.38	181.10	209.66	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	35.02	165.38	193.09	7.29	4.4
		EL 1	102.1	47 W T5 & 1 BF Prog	37.93	158.83	192.21	8.18	3.7
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	73.24	181.10	234.17	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	82.51	181.10	243.44	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.14	165.38	226.87	7.29	4.4
		EL 1	102.1	47 W T5 & 1 BF Prog	92.06	158.83	225.99	8.18	3.7
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	76.04	181.10	235.91	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	85.31	181.10	245.18	-9.27	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	91.94	165.38	228.62	7.29	4.4
		EL 1	102.1	47 W T5 & 1 BF Prog	94.85	158.83	227.74	8.18	3.7

8B.7.3.3 Product Class: 4-foot T5 miniature bipin standard output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the 4-foot T5 MiniBP SO lamps with CCT less than or equal to 4,500 K with volatile rare earth prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.63 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.84	152.84	168.85	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	20.95	152.84	173.96	-5.12	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	24.02	152.84	177.03	-8.18	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	27.16	143.23	170.56	-1.72	6.9
		EL 2	25.0	25 W T5 & 1 BF Prog	29.91	137.88	164.88	3.97	5.5
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.74	152.84	206.28	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	73.85	134.13	192.69	13.59	1.6
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	76.92	134.13	195.75	10.53	2.6
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.06	125.79	190.56	15.72	2.5
		EL 2	25.0	25 W T5 & 0.85 BF Prog	82.81	121.15	185.57	20.71	2.6
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	71.53	152.84	208.26	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	76.65	134.13	194.67	13.59	1.6
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	79.72	134.13	197.73	10.53	2.6
		EL 2	26.0	26 W T5 & 0.85 BF Prog	82.86	125.79	192.53	15.72	2.5
		EL 2	25.0	25 W T5 & 0.85 BF Prog	85.61	121.15	187.55	20.71	2.6

Table 8B.7.64 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.84	109.55	125.55	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	20.96	109.55	130.67	-5.12	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	24.03	109.55	133.74	-8.19	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	27.17	102.66	130.00	-4.44	8.4
		EL 2	25.0	25 W T5 & 1 BF Prog	29.92	98.83	125.90	-0.34	6.7
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.75	109.55	163.35	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	73.87	96.14	155.06	8.29	1.9
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	76.94	96.14	158.13	5.22	3.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.08	90.16	155.29	8.06	3.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	82.83	86.83	151.70	11.65	3.2
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	71.55	109.55	165.35	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	76.66	96.14	157.06	8.29	1.9
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	79.73	96.14	160.13	5.22	3.1
		EL 2	26.0	26 W T5 & 0.85 BF Prog	82.88	90.16	157.29	8.06	3.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	85.63	86.83	153.70	11.65	3.2

8B.7.3.4 Product Class: 8-foot single pin slimline ≤ 4,500 K

The following tables present the LCC savings and PBP results for the 8-foot SP slimline lamps with CCT less than or equal to 4,500 K with volatile rare earth prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.65 LCC and PBP Results for a Two-Lamp 8-foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	28.44	219.51	248.30	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	35.11	219.51	254.97	-6.67	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	40.66	219.51	260.52	-12.22	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	51.50	208.16	260.01	-11.71	9.7
		EL 2	108.0	50 W T8 & 0.87 BF Inst	58.85	193.01	252.22	-3.92	5.5
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	104.18	216.15	290.29	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	110.85	193.01	273.82	16.47	1.4
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	116.40	193.01	279.37	10.92	2.5
		EL 2	105.6	54 W T8 & 0.77 BF Inst	127.24	183.01	280.21	10.08	3.3
		EL 2	108.0	50 W T8 & 0.87 BF Inst	134.60	189.96	294.52	-4.23	5.5
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	106.97	216.15	291.96	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	113.64	193.01	275.49	16.47	1.4
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	119.19	193.01	281.04	10.92	2.5
		EL 2	105.6	54 W T8 & 0.77 BF Inst	130.03	183.01	281.89	10.08	3.3
		EL 2	108.0	50 W T8 & 0.87 BF Inst	137.39	189.96	296.19	-4.23	5.5

Table 8B.7.66 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	28.45	157.75	186.55	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	35.12	157.75	193.22	-6.67	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	40.67	157.75	198.77	-12.22	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	51.51	149.59	201.45	-14.91	11.8
		EL 2	108.0	50 W T8 & 0.87 BF Inst	58.87	138.70	197.93	-11.38	6.6
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	104.19	155.33	229.81	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	110.87	138.70	219.86	9.96	1.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	116.42	138.70	225.41	4.40	3.1
		EL 2	105.6	54 W T8 & 0.77 BF Inst	127.26	131.52	229.07	0.74	4.0
		EL 2	108.0	50 W T8 & 0.87 BF Inst	134.62	136.51	241.42	-11.61	6.7
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	106.99	155.33	231.50	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	113.66	138.70	221.54	9.96	1.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	119.21	138.70	227.10	4.40	3.1
		EL 2	105.6	54 W T8 & 0.77 BF Inst	130.06	131.52	230.76	0.74	4.0
		EL 2	108.0	50 W T8 & 0.87 BF Inst	137.42	136.51	243.11	-11.61	6.7

8B.7.3.5 Product Class: 8-foot recessed double contact HO $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the 8-foot RDC HO lamps with CCT less than or equal to 4,500 K with volatile rare earth prices. Key inputs consist of using *AEO 2013* reference case electricity prices.

Table 8B.7.67 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	26.16	238.37	264.92	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	35.72	238.37	274.48	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	46.92	238.37	285.68	-20.76	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	102.05	238.37	300.25	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	111.61	238.37	309.81	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	122.80	238.37	321.01	-20.76	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	104.84	238.37	301.55	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	114.40	238.37	311.11	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	125.60	238.37	322.31	-20.76	NER

Table 8B.7.68 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector with Volatile Rare Earth Prices

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	26.17	171.55	198.10	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	35.73	171.55	207.66	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	46.93	171.55	218.86	-20.76	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	102.06	171.55	235.30	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	111.62	171.55	244.86	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	122.83	171.55	256.07	-20.76	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	104.86	171.55	236.67	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	114.42	171.55	246.24	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	125.62	171.55	257.44	-20.76	NER

8B.7.4 Electricity Price Trend Case Results

DOE analyzed the impacts of high and low growth trends for future electricity prices, as lamp and lamp-and-ballast system operating costs are directly related to future electricity prices. Specifically, DOE examined the impacts of using high-economic-growth and low-economic-growth cases generated utilizing the *AEO 2013* dataset. Chapter 8 of this TSD describes and compares the three price trends. The following tables present LCC savings and PBP results using the high and low growth cases.

8B.7.4.1 Product Class: 4-foot medium bipin $\leq$ 4,500 K

The following tables present the LCC savings and PBP results of the 4-foot MBP lamps with CCT less than or equal to 4,500 K, considering *AEO 2013* high and low growth price trend cases. Key inputs consist of using average-weighted lamp prices.

Table 8B.7.69 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	119.35	136.71	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	33.38	119.35	141.01	-4.29	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.79	100.00	129.97	6.74	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.73	119.35	146.26	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	23.99	107.26	131.43	5.28	2.7
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	59.99	117.83	161.10	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	76.18	105.38	152.95	8.15	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.59	98.67	154.55	6.55	3.2
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.53	103.12	155.94	5.16	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.79	104.03	154.11	6.99	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.78	117.83	162.79	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.97	105.38	154.64	8.15	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.39	98.67	156.24	6.55	3.2
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.33	103.12	157.63	5.16	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.58	104.03	155.80	6.99	2.4

Table 8B.7.70 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	118.00	135.37	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	33.38	118.00	139.66	-4.29	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.79	98.87	128.84	6.52	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.73	118.00	144.91	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	23.99	106.05	130.22	5.15	2.7
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	59.99	116.49	159.77	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	76.18	104.19	151.75	8.01	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.59	97.55	153.43	6.33	3.2
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.53	101.95	154.77	4.99	3.1
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.79	102.86	152.93	6.84	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.78	116.49	161.46	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.97	104.19	153.45	8.01	0.4
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.39	97.55	155.13	6.33	3.2
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.33	101.95	156.46	4.99	3.1
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.58	102.86	154.62	6.84	2.4

Table 8B.7.71 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	86.71	104.08	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	32.69	86.71	107.80	-3.73	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.80	72.65	102.63	1.45	3.8
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.74	86.71	113.63	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	24.00	77.93	102.10	1.98	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	60.00	85.60	129.07	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	75.49	76.56	123.75	5.31	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.61	71.69	127.76	1.31	3.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.55	74.92	127.93	1.13	3.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.80	75.58	125.85	3.22	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.79	85.60	130.77	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.29	76.56	125.45	5.31	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.40	71.69	129.46	1.31	3.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.34	74.92	129.64	1.13	3.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.60	75.58	127.55	3.22	2.9

Table 8B.7.72 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	17.19	83.92	101.29	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Inst	32.69	83.92	105.01	-3.73	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	29.80	70.31	100.29	0.99	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Inst	26.74	83.92	110.84	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Inst	24.00	75.42	99.59	1.69	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	60.00	82.85	126.31	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	75.49	74.10	121.29	5.02	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	72.61	69.38	125.45	0.86	3.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	69.55	72.51	125.52	0.79	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	66.80	73.15	123.42	2.89	2.9
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Inst	62.79	82.85	128.02	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	78.29	74.10	122.99	5.02	0.5
		EL 2	93.0	26.6 W T8 & 0.88 BF Inst	75.40	69.38	127.16	0.86	3.9
		EL 2	95.4	32.5 W T8 & 0.77 BF Inst	72.34	72.51	127.22	0.79	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	69.60	73.15	125.12	2.89	2.9

Table 8B.7.73 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	183.15	200.49	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	31.26	183.15	206.60	-6.11	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.79	153.77	183.72	16.77	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.73	183.15	210.04	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	23.99	164.80	188.94	11.55	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.19	183.15	238.38	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.27	183.15	244.49	-6.11	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.27	153.99	215.33	23.05	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.80	153.77	221.60	16.77	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.74	183.15	247.93	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.74	153.99	218.77	19.61	2.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	67.99	164.80	226.83	11.55	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.98	183.15	240.79	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	78.06	183.15	246.90	-6.11	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	78.06	153.99	217.74	23.05	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.59	153.77	224.01	16.77	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.53	183.15	250.33	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.53	153.99	221.18	19.61	2.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.79	164.80	229.24	11.55	2.8

Table 8B.7.74 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	179.12	196.46	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	31.26	179.12	202.58	-6.11	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.79	150.39	180.34	16.13	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.73	179.12	206.01	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	23.99	161.18	185.32	11.14	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.19	179.12	234.35	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.27	179.12	240.46	-6.11	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.27	150.61	211.95	22.41	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.80	150.39	218.22	16.13	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.74	179.12	243.90	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.74	150.61	215.38	18.97	2.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	67.99	161.18	223.21	11.14	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.98	179.12	236.76	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	78.06	179.12	242.87	-6.11	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	78.06	150.61	214.35	22.41	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.59	150.39	220.63	16.13	3.2
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.53	179.12	246.31	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.53	150.61	217.79	18.97	2.4
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.79	161.18	225.61	11.14	2.8

Table 8B.7.75 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	132.75	150.09	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	30.99	132.75	156.29	-6.20	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.80	111.46	141.41	8.69	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.74	132.75	159.64	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	24.00	119.45	143.60	6.50	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.20	132.75	188.28	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.00	132.75	194.48	-6.20	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.00	111.62	173.34	14.93	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.81	111.46	179.59	8.69	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.75	132.75	197.83	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.75	111.62	176.69	11.58	2.9
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	68.00	119.45	181.78	6.50	3.3
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.99	132.75	190.70	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	77.79	132.75	196.90	-6.20	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	77.79	111.62	175.77	14.93	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.61	111.46	182.02	8.69	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.55	132.75	200.26	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.55	111.62	179.12	11.58	2.9
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.80	119.45	184.21	6.50	3.3

Table 8B.7.76 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	17.19	126.91	144.24	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	30.99	126.91	150.44	-6.20	NER
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	29.80	106.55	136.50	7.75	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	26.74	126.91	153.80	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	24.00	114.19	138.33	5.91	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	61.20	126.91	182.43	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	75.00	126.91	188.63	-6.20	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	75.00	106.70	168.43	14.00	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	73.81	106.55	174.68	7.75	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	70.75	126.91	191.98	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	70.75	106.70	171.78	10.65	3.0
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	68.00	114.19	176.52	5.91	3.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.88 BF Prog	63.99	126.91	184.86	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.88 BF Prog	77.79	126.91	191.06	-6.20	NER
		EL 1	90.0	32.5 W T8 & 0.72 BF Prog	77.79	106.70	170.85	14.00	0.3
		EL 2	93.0	26.6 W T8 & 0.88 BF Prog	76.61	106.55	177.11	7.75	3.9
		EL 2	95.4	32.5 W T8 & 0.88 BF Prog	73.55	126.91	194.41	-9.55	NER
		EL 2	95.4	32.5 W T8 & 0.72 BF Prog	73.55	106.70	174.20	10.65	3.0
		EL 2	96.0	28.4 W T8 & 0.88 BF Prog	70.80	114.19	178.95	5.91	3.4

Table 8B.7.77 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.95	230.39	258.71	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	55.06	230.39	266.12	-7.41	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.17	192.84	246.37	12.33	3.3
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	47.05	230.39	277.80	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.56	206.94	248.85	9.85	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.30	228.50	292.13	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	113.40	206.58	277.62	14.51	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.51	191.19	280.03	12.09	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.39	199.80	282.52	9.60	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.90	205.19	282.42	9.71	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.09	228.50	293.82	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	116.20	206.58	279.31	14.51	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.31	191.19	281.73	12.09	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.19	199.80	284.22	9.60	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.70	205.19	284.12	9.71	2.8

Table 8B.7.78 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.95	227.79	256.10	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	55.06	227.79	263.51	-7.41	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.17	190.66	244.19	11.91	3.3
		EL 3	95.4	32.5 W T8 & 0.87 BF Inst	47.05	227.79	275.20	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.56	204.60	246.51	9.59	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.30	225.92	289.55	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	113.40	204.24	275.28	14.26	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.51	189.03	277.87	11.67	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.39	197.54	280.27	9.28	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.90	202.87	280.10	9.44	2.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.09	225.92	291.24	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	116.20	204.24	276.98	14.26	0.5
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.31	189.03	279.56	11.67	3.3
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.19	197.54	281.96	9.28	3.2
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.70	202.87	281.80	9.44	2.8

Table 8B.7.79 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.96	167.39	195.70	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	53.92	167.39	202.18	-6.48	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.19	140.11	193.65	2.06	3.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	47.07	167.39	214.81	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.57	150.34	192.27	3.43	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.31	166.01	229.90	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.27	150.08	220.45	9.45	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.54	138.91	228.02	1.88	4.0
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.42	145.16	228.15	1.75	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.92	149.08	226.57	3.33	3.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.11	166.01	231.60	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	115.07	150.08	222.16	9.45	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.34	138.91	229.72	1.88	4.0
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.21	145.16	229.86	1.75	3.9
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.72	149.08	228.28	3.33	3.4

Table 8B.7.80 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	27.96	162.00	190.32	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	53.92	162.00	196.80	-6.48	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	53.19	135.60	189.14	1.18	4.0
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	47.07	162.00	209.42	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	41.57	145.50	187.43	2.89	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	86.31	160.67	224.56	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	112.27	145.25	215.62	8.94	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	111.54	134.44	223.55	1.01	4.0
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	105.42	140.49	223.48	1.08	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	99.92	144.28	221.78	2.78	3.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	89.11	160.67	226.26	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.78 BF Inst	115.07	145.25	217.33	8.94	0.6
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	114.34	134.44	225.25	1.01	4.0
		EL 2	95.4	32.5 W T8 & 0.74 BF Inst	108.21	140.49	225.18	1.08	4.0
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	102.72	144.28	223.48	2.78	3.5

Table 8B.7.81 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.95	363.36	391.63	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.55	363.36	402.05	-10.42	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.17	304.69	358.17	33.45	3.2
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.05	363.36	410.72	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.56	326.72	368.59	23.04	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.14	363.36	443.45	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.73	347.18	437.70	5.76	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.36	304.69	410.00	33.45	3.2
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.24	347.18	446.37	-2.92	8.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.75	311.89	405.59	37.86	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.94	363.36	445.86	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.53	347.18	440.10	5.76	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.15	304.69	412.41	33.45	3.2
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.03	347.18	448.78	-2.92	8.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.54	311.89	408.00	37.86	2.0

Table 8B.7.82 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.95	355.37	383.64	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.55	355.37	394.06	-10.42	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.17	298.00	351.48	32.16	3.2
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.05	355.37	402.73	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.56	319.53	361.40	22.24	2.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.14	355.37	435.46	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.73	339.55	430.06	5.40	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.36	298.00	403.30	32.16	3.2
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.24	339.55	438.74	-3.27	8.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.75	305.04	398.73	36.73	2.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.94	355.37	437.87	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.53	339.55	432.47	5.40	1.0
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.15	298.00	405.71	32.16	3.2
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.03	339.55	441.15	-3.27	8.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.54	305.04	401.14	36.73	2.0

Table 8B.7.83 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.96	263.38	291.64	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.11	263.38	302.21	-10.57	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.19	220.86	274.34	17.30	3.9
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.07	263.38	310.74	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.57	236.82	278.68	12.95	3.3
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.16	263.38	343.87	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.30	251.65	342.72	1.15	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.38	220.86	326.57	17.30	3.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.26	251.65	351.25	-7.38	10.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.77	226.07	320.17	23.70	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.95	263.38	346.30	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.10	251.65	345.14	1.15	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.18	220.86	329.00	17.30	3.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.06	251.65	353.67	-7.38	10.6
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.56	226.07	322.60	23.70	2.4

Table 8B.7.84 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	27.96	251.78	280.04	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.89 BF Prog	51.11	251.78	290.61	-10.57	NER
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	53.19	211.13	264.61	15.43	3.9
		EL 2	95.4	32.5 W T8 & 0.89 BF Prog	47.07	251.78	299.14	-19.10	NER
		EL 2	96.0	28.4 W T8 & 0.89 BF Prog	41.57	226.39	268.25	11.78	3.4
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	88.16	251.78	332.27	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	111.30	240.57	331.63	0.64	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	113.38	211.13	316.84	15.43	3.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	107.26	240.57	340.16	-7.89	10.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	101.77	216.12	310.22	22.05	2.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.89 BF Prog	90.95	251.78	334.69	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.87 BF Prog	114.10	240.57	334.06	0.64	1.2
		EL 2	93.0	26.6 W T8 & 0.89 BF Prog	116.18	211.13	319.27	15.43	3.9
		EL 2	95.4	32.5 W T8 & 0.87 BF Prog	110.06	240.57	342.59	-7.89	10.8
		EL 2	96.0	28.4 W T8 & 0.87 BF Prog	104.56	216.12	312.64	22.05	2.4

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K operating in the residential sector under the *AEO 2013* high and low growth electricity price trend cases. Key inputs consist of using average-weighted lamp prices. Residential average operating hours were used with an analysis period of 15 years.

Table 8B.7.85 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	10.48	47.33	57.82	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	11.58	47.33	58.91	-1.09	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	23.09	39.70	62.79	-4.97	17.5
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	20.03	47.33	67.36	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	17.29	42.56	59.85	-2.03	15.1
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	52.71	47.33	100.05	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	53.80	44.93	98.74	1.31	4.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	65.32	39.70	105.01	-4.97	17.5
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	62.26	44.93	107.19	-7.15	42.3
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	59.51	40.40	99.91	0.13	10.4
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.51	47.33	102.84	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.60	44.93	101.53	1.31	4.8
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	68.11	39.70	107.81	-4.97	17.5
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	65.05	44.93	109.99	-7.15	42.3
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	62.31	40.40	102.71	0.13	10.4

Table 8B.7.86 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Instant Start System Operating in the Residential Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	10.48	47.30	57.79	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.87 BF Inst	11.58	47.30	58.88	-1.09	NER
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	23.09	39.67	62.76	-4.97	17.1
		EL 2	95.4	32.5 W T8 & 0.87 BF Inst	20.03	47.30	67.33	-9.55	NER
		EL 2	96.0	28.4 W T8 & 0.87 BF Inst	17.29	42.54	59.82	-2.03	14.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	52.71	47.30	100.01	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	53.80	44.90	98.71	1.31	4.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	65.32	39.67	104.99	-4.97	17.1
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	62.26	44.90	107.16	-7.15	41.3
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	59.51	40.37	99.89	0.13	10.2
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.87 BF Inst	55.51	47.30	102.81	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.83 BF Inst	56.60	44.90	101.50	1.31	4.7
		EL 2	93.0	26.6 W T8 & 0.87 BF Inst	68.11	39.67	107.78	-4.97	17.1
		EL 2	95.4	32.5 W T8 & 0.83 BF Inst	65.05	44.90	109.96	-7.15	41.3
		EL 2	96.0	28.4 W T8 & 0.83 BF Inst	62.31	40.37	102.68	0.13	10.2

8B.7.4.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for 4-foot T5 MiniBP HO lamps with CCT less than or equal to 4,500 K under the *AEO 2013* high growth and low growth electricity price trend cases. Key inputs consist of using average-weighted lamp prices.

Table 8B.7.87 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector under the *AEO 2013* High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.57	257.63	276.38	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.59	257.63	284.39	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.51	235.27	260.93	15.45	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	35.42	225.94	257.08	19.30	2.7
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.68	257.63	309.92	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.70	257.63	317.94	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.62	235.27	294.47	15.45	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	89.53	225.94	290.62	19.30	2.7
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.47	257.63	311.65	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.49	257.63	319.67	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.41	235.27	296.20	15.45	3.2
		EL 1	102.1	47 W T5 & 1 BF Prog	92.32	225.94	292.36	19.30	2.7

Table 8B.7.88 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.57	254.50	273.25	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.59	254.50	281.26	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.51	232.41	258.07	15.18	3.1
		EL 1	102.1	47 W T5 & 1 BF Prog	35.42	223.20	254.33	18.91	2.7
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.68	254.50	306.79	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.70	254.50	314.81	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.62	232.41	291.61	15.18	3.1
		EL 1	102.1	47 W T5 & 1 BF Prog	89.53	223.20	287.88	18.91	2.7
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.47	254.50	308.52	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.49	254.50	316.54	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.41	232.41	293.34	15.18	3.1
		EL 1	102.1	47 W T5 & 1 BF Prog	92.32	223.20	289.61	18.91	2.7

Table 8B.7.89 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.58	186.91	205.66	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.60	186.91	213.69	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.52	170.69	196.43	9.23	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	35.43	163.93	195.12	10.55	3.2
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.69	186.91	239.44	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.72	186.91	247.46	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.64	170.69	230.20	9.23	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	89.55	163.93	228.89	10.55	3.2
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.49	186.91	241.18	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.51	186.91	249.21	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.43	170.69	231.95	9.23	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	92.35	163.93	230.64	10.55	3.2

Table 8B.7.90 LCC and PBP Results for a Two-Lamp 4-Foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	18.58	180.70	199.46	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	26.60	180.70	207.48	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	32.52	165.02	190.76	8.70	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	35.43	158.48	189.67	9.78	3.3
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	72.69	180.70	233.23	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 1 BF Prog	80.72	180.70	241.25	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	86.64	165.02	224.54	8.70	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	89.55	158.48	223.45	9.78	3.3
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 1 BF Prog	75.49	180.70	234.98	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 1 BF Prog	83.51	180.70	243.00	-8.02	NER
		EL 1	102.0	49 W T5 & 1 BF Prog	89.43	165.02	226.28	8.70	3.8
		EL 1	102.1	47 W T5 & 1 BF Prog	92.35	158.48	225.19	9.78	3.3

8B.7.4.3 Product Class: 4-foot T5 miniature bipin standard output $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for 4-foot T5 MiniBP SO lamps with CCT less than or equal to 4,500 K under the AEO 2013 high growth and low growth electricity price trend cases. Key inputs consist of using average-weighted lamp prices.

Table 8B.7.91 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.30	156.17	171.65	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.17	156.17	175.51	-3.87	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.52	156.17	177.87	-6.22	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.67	146.35	171.19	0.45	5.6
		EL 2	25.0	25 W T5 & 1 BF Prog	27.41	140.89	165.64	6.00	4.7
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.19	156.17	209.07	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.06	137.06	193.82	15.25	1.2
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.41	137.06	196.18	12.89	1.9
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.56	128.53	190.79	18.28	2.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.30	123.79	185.96	23.11	2.2
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	70.99	156.17	211.05	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.86	137.06	195.80	15.25	1.2
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.21	137.06	198.15	12.89	1.9
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.35	128.53	192.77	18.28	2.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.10	123.79	187.94	23.11	2.2

Table 8B.7.92 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.30	153.69	169.17	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.17	153.69	173.03	-3.87	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.52	153.69	175.39	-6.22	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.67	144.03	168.87	0.30	5.6
		EL 2	25.0	25 W T5 & 1 BF Prog	27.41	138.65	163.40	5.76	4.7
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.19	153.69	206.59	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.06	134.88	191.65	14.94	1.2
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.41	134.88	194.00	12.59	1.9
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.56	126.49	188.75	17.84	2.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.30	121.82	184.00	22.59	2.2
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	70.99	153.69	208.57	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.86	134.88	193.62	14.94	1.2
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.21	134.88	195.98	12.59	1.9
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.35	126.49	190.73	17.84	2.0
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.10	121.82	185.98	22.59	2.2

Table 8B.7.93 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.30	113.23	128.70	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.17	113.23	132.57	-3.87	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.53	113.23	134.93	-6.22	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.67	106.11	130.95	-2.25	6.8
		EL 2	25.0	25 W T5 & 1 BF Prog	27.42	102.15	126.97	1.73	5.6
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.21	113.23	166.50	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.08	99.37	156.51	9.99	1.4
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.43	99.37	158.86	7.64	2.3
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.58	93.19	155.82	10.67	2.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.32	89.75	152.36	14.13	2.7
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	71.00	113.23	168.49	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.87	99.37	158.50	9.99	1.4
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.23	99.37	160.86	7.64	2.3
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.37	93.19	157.82	10.67	2.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.12	89.75	154.36	14.13	2.7

Table 8B.7.94 LCC and PBP Results for a Two-Lamp 4-Foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	15.30	108.98	124.46	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 1 BF Prog	19.17	108.98	128.33	-3.87	NER
		EL 2	27.8	27.8 W T5 & 1 BF Prog	21.53	108.98	130.68	-6.22	NER
		EL 2	26.0	26 W T5 & 1 BF Prog	24.67	102.13	126.97	-2.52	6.9
		EL 2	25.0	25 W T5 & 1 BF Prog	27.42	98.32	123.14	1.32	5.7
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	68.21	108.98	162.25	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	72.08	95.64	152.78	9.47	1.5
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	74.43	95.64	155.13	7.12	2.3
		EL 2	26.0	26 W T5 & 0.85 BF Prog	77.58	89.69	152.33	9.92	2.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	80.32	86.38	149.00	13.25	2.7
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 1 BF Prog	71.00	108.98	164.24	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.85 BF Prog	74.87	95.64	154.77	9.47	1.5
		EL 2	27.8	27.8 W T5 & 0.85 BF Prog	77.23	95.64	157.13	7.12	2.3
		EL 2	26.0	26 W T5 & 0.85 BF Prog	80.37	89.69	154.32	9.92	2.4
		EL 2	25.0	25 W T5 & 0.85 BF Prog	83.12	86.38	150.99	13.25	2.7

8B.7.4.4 Product Class: 8-foot single pin slimline $\leq 4,500$ K

The following tables present the LCC savings and PBP results for 8-foot SP slimline lamps with CCT less than or equal to 4,500 K under the *AEO 2013* high growth and low growth electricity price trend cases. Key inputs consist of using average-weighted lamp prices.

Table 8B.7.95 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector under the *AEO 2013* High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.72	223.96	251.04	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.40	223.96	253.72	-2.68	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.52	223.96	258.84	-7.80	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.51	212.38	256.24	-5.20	6.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.87	196.92	248.14	2.90	4.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.46	220.53	292.95	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.14	196.92	272.02	20.93	0.5
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.25	196.92	277.14	15.81	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.24	186.72	275.93	17.02	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.60	193.81	290.38	2.58	4.3
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.25	220.53	294.63	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.93	196.92	273.70	20.93	0.5
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.05	196.92	278.82	15.81	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.04	186.72	277.61	17.02	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.40	193.81	292.05	2.58	4.3

Table 8B.7.96 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.72	221.52	248.60	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.40	221.52	251.27	-2.68	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.52	221.52	256.39	-7.80	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.51	210.06	253.93	-5.33	6.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.87	194.77	245.99	2.60	4.3
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.46	218.12	290.55	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.14	194.77	269.88	20.67	0.5
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.25	194.77	274.99	15.55	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.24	184.69	273.89	16.65	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.60	191.70	288.26	2.29	4.3
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.25	218.12	292.22	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.93	194.77	271.55	20.67	0.5
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.05	194.77	276.67	15.55	1.6
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.04	184.69	275.57	16.65	2.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.40	191.70	289.94	2.29	4.3

Table 8B.7.97 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.73	162.73	189.82	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.41	162.73	192.49	-2.68	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.53	162.73	197.61	-7.80	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.52	154.31	198.19	-8.37	8.4
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.88	143.08	194.32	-4.50	5.2
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.47	160.24	233.00	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.15	143.09	218.53	14.47	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.27	143.09	223.65	9.35	1.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.26	135.67	225.23	7.77	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.62	140.82	237.74	-4.74	5.2
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.27	160.24	234.69	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.95	143.09	220.22	14.47	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.07	143.09	225.34	9.35	1.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.06	135.67	226.92	7.77	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.42	140.82	239.43	-4.74	5.2

Table 8B.7.98 LCC and PBP Results for a Two-Lamp 8-Foot 59 W T8 Single Pin Slimline System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	26.73	157.56	184.64	N/A	N/A
	Lamp Replacement	EL 1	98.2	60.1 W T8 & 0.87 BF Inst	29.41	157.56	187.32	-2.68	NER
		EL 2	99.0	60.1 W T8 & 0.87 BF Inst	34.53	157.56	192.44	-7.80	NER
		EL 2	105.6	54 W T8 & 0.87 BF Inst	43.52	149.41	193.29	-8.64	8.5
		EL 2	108.0	50 W T8 & 0.87 BF Inst	50.88	138.53	189.77	-5.13	5.2
Event II: Ballast Failure	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	102.47	155.14	227.91	N/A	N/A
	Lamp & Ballast Replacement	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	105.15	138.54	213.98	13.93	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	110.27	138.54	219.10	8.81	1.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	119.26	131.36	220.92	6.99	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	126.62	136.35	233.26	-5.35	5.3
Event III: New Construction and Renovation	Baseline	Baseline	96.5	60.1 W T8 & 0.87 BF Inst	105.27	155.14	229.60	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	98.2	60.1 W T8 & 0.77 BF Inst	107.95	138.54	215.67	13.93	0.7
		EL 2	99.0	60.1 W T8 & 0.77 BF Inst	113.07	138.54	220.79	8.81	1.9
		EL 2	105.6	54 W T8 & 0.77 BF Inst	122.06	131.36	222.60	6.99	2.9
		EL 2	108.0	50 W T8 & 0.87 BF Inst	129.42	136.35	234.95	-5.35	5.3

8B.7.4.5 Product Class: 8-foot recessed double contact HO $\leq$ 4,500 K

The following tables present the LCC savings and PBP results for the 8-foot RDC HO lamps with CCT less than or equal to 4,500 K under the *AEO 2013* high growth and low growth electricity price trend cases. Key inputs consist of using average-weighted lamp prices.

Table 8B.7.99 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector under the *AEO 2013* High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	242.92	267.76	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.00	242.92	277.32	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.21	242.92	284.52	-16.76	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.33	242.92	303.09	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.89	242.92	312.65	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.09	242.92	319.85	-16.76	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.13	242.92	304.39	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.68	242.92	313.95	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.89	242.92	321.15	-16.76	NER

Table 8B.7.100 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	241.48	266.32	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.00	241.48	275.88	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.21	241.48	283.08	-16.76	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.33	241.48	301.65	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.89	241.48	311.21	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.09	241.48	318.41	-16.76	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.13	241.48	302.95	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.68	241.48	312.51	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.89	241.48	319.71	-16.76	NER

Table 8B.7.101 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	176.63	201.46	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.01	176.63	211.02	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.22	176.63	218.23	-16.77	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.34	176.63	238.66	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.90	176.63	248.23	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.11	176.63	255.43	-16.77	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.14	176.63	240.04	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.70	176.63	249.60	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.91	176.63	256.80	-16.77	NER

Table 8B.7.102 LCC and PBP Results for a Two-Lamp 8-Foot 86 W T8 Recessed Double Contact HO System Operating in the Industrial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	24.45	171.92	196.75	N/A	N/A
	Lamp Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	34.01	171.92	206.31	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	41.22	171.92	213.52	-16.77	NER
Event II: Ballast Failure	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	100.34	171.92	233.95	N/A	N/A
	Lamp & Ballast Replacement	EL 1	95.2	84 W T8 & 0.81 BF Inst	109.90	171.92	243.52	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	117.11	171.92	250.72	-16.77	NER
Event III: New Construction and Renovation	Baseline	Baseline	92.0	84 W T8 & 0.81 BF Inst	103.14	171.92	235.32	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	95.2	84 W T8 & 0.81 BF Inst	112.70	171.92	244.89	-9.56	NER
		EL 2	97.6	84 W T8 & 0.81 BF Inst	119.91	171.92	252.09	-16.77	NER

8B.7.5 Dimming Results

DOE assessed the impacts of dimmers on GSFLs by determining the reduction in system lumen output and system input power as a result of using dimming ballasts. In this scenario, DOE assumed consumers will use the dimmer to equalize the lumen output to that of the baseline lamp. (See appendix 6A of this NOPR TSD for an assessment of the performance characteristics and annual energy consumption for GSFL dimming.)

8B.7.5.1 Product Class: 4-foot medium bipin $\leq 4,500$ K

The following tables present the LCC savings and PBP results for the 4-foot MBP lamps with CCT less than or equal to 4,500 K operated on a dimmer. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.103 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	17.19	134.44	151.78	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	31.26	132.86	156.31	-4.54	5.1
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	29.79	117.36	147.31	4.47	5.5
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	26.73	127.19	154.08	-2.31	9.8
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	23.99	120.87	145.01	6.77	3.7
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	81.77	134.44	207.39	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	95.85	132.86	211.92	-4.54	5.1
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	94.38	117.36	202.92	4.47	5.5
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	91.32	127.19	209.70	-2.31	9.8
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	88.57	120.87	200.62	6.77	3.7
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	84.57	134.44	209.80	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	98.64	132.86	214.33	-4.54	5.1
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	97.17	117.36	205.33	4.47	5.5
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	94.11	127.19	212.10	-2.31	9.8
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	91.37	120.87	203.03	6.77	3.7

Table 8B.7.104 LCC and PBP Results for a 2-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	17.19	96.28	113.62	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	30.99	95.16	118.70	-5.07	6.2
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	29.80	84.05	114.01	-0.38	6.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	26.74	91.10	117.99	-4.37	11.9
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	24.00	86.57	110.71	2.91	4.5
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	81.79	96.28	169.68	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	95.59	95.16	174.75	-5.07	6.2
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	94.40	84.05	170.06	-0.38	6.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	91.34	91.10	174.04	-4.37	11.9
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	88.59	86.57	166.76	2.91	4.5
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	84.58	96.28	172.10	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	98.38	95.16	177.17	-5.07	6.2
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	97.20	84.05	172.48	-0.38	6.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	94.14	91.10	176.47	-4.37	11.9
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	91.39	86.57	169.19	2.91	4.5

Table 8B.7.105 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Commercial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	27.95	259.42	287.68	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	51.55	256.38	295.06	-7.38	5.3
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	53.17	235.66	289.14	-1.46	7.9
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	47.05	245.44	292.80	-5.12	10.1
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	41.56	234.13	276.00	11.68	4.0
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	115.07	259.42	362.69	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	138.66	256.38	370.07	-7.38	5.3
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	140.28	235.66	364.15	-1.46	7.9
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	134.16	245.44	367.81	-5.12	10.1
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	128.67	234.13	351.01	11.68	4.0
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	117.86	259.42	365.10	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	141.45	256.38	372.48	-7.38	5.3
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	143.08	235.66	366.56	-1.46	7.9
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	136.96	245.44	370.22	-5.12	10.1
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	131.47	234.13	353.42	11.68	4.0

Table 8B.7.106 LCC and PBP Results for a 4-Lamp 4-foot 32 W T8 Medium Bipin Programmed Start System Operating in the Industrial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	27.96	185.80	214.06	N/A	N/A
	Lamp Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	51.11	183.62	222.45	-8.40	6.5
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	53.19	168.79	222.27	-8.21	9.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	47.07	175.79	223.15	-9.09	12.3
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	41.57	167.69	209.56	4.50	4.8
Event II: Ballast Failure	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	115.09	185.80	289.66	N/A	N/A
	Lamp & Ballast Replacement	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	138.24	183.62	298.06	-8.40	6.5
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	140.32	168.79	297.87	-8.21	9.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	134.20	175.79	298.75	-9.09	12.3
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	128.70	167.69	285.16	4.50	4.8
Event III: New Construction and Renovation	Baseline	Baseline	89.2	32.5 W T8 & 0.59 BF Prog	117.89	185.80	292.09	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	90.0	32.5 W T8 & 0.58 BF Prog	141.03	183.62	300.48	-8.40	6.5
		EL 2	93.0	26.6 W T8 & 0.68 BF Prog	143.11	168.79	300.30	-8.21	9.6
		EL 2	95.4	32.5 W T8 & 0.55 BF Prog	136.99	175.79	301.18	-9.09	12.3
		EL 2	96.0	28.4 W T8 & 0.62 BF Prog	131.50	167.69	287.59	4.50	4.8

8B.7.5.2 Product Class: 4-foot T5 miniature bipin high output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for 4-foot T5 MiniBP HO lamps with CCT less than or equal to 4,500 K operated on a dimmer. Key inputs consist of using *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.107 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Commercial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	18.57	182.02	200.77	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	26.59	167.44	194.21	6.57	2.8
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	105.39	182.02	254.59	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	113.41	167.44	248.03	6.57	2.8
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	108.19	182.02	256.33	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	116.21	167.44	249.76	6.57	2.8

Table 8B.7.108 LCC and PBP Results for a Two-Lamp 4-foot 54 W T5 Miniature Bipin High Output System Operating in the Industrial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	18.58	130.59	149.34	N/A	N/A
	Lamp Replacement	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	26.60	120.13	146.90	2.44	3.4
Event II: Ballast Failure	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	105.42	130.59	203.54	N/A	N/A
	Lamp & Ballast Replacement	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	113.44	120.13	201.10	2.44	3.4
Event III: New Construction and Renovation	Baseline	Baseline	83.6	53.8 W T5 & 0.67 BF Prog	108.21	130.59	205.28	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	92.9	53.8 W T5 & 0.60 BF Prog	116.24	120.13	202.84	2.44	3.4

8B.7.5.3 Product Class: 4-foot T5 miniature bipin standard output $\leq 4,500$ K

The following tables present the LCC savings and PBP results for 4-foot T5 MiniBP SO lamps with CCT less than or equal to 4,500 K operated on a dimmer. Key inputs consist of using *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.7.109 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Commercial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	15.30	113.04	128.51	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	19.17	104.75	124.09	4.43	2.7
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	21.52	99.15	120.84	7.68	2.6
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	99.44	113.04	188.05	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	103.31	104.75	183.62	4.43	2.7
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	105.67	99.15	180.38	7.68	2.6
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	102.24	113.04	190.03	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	106.11	104.75	185.60	4.43	2.7
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	108.46	99.15	182.35	7.68	2.6

Table 8B.7.110 LCC and PBP Results for a Two-Lamp 4-foot 28 W T5 Miniature Bipin Standard Output System Operating in the Industrial Sector with a Dimmer

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Design Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	15.30	81.02	96.49	N/A	N/A
	Lamp Replacement	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	19.17	75.08	94.42	2.08	3.3
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	21.53	71.06	92.76	3.74	3.2
Event II: Ballast Failure	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	99.47	81.02	156.62	N/A	N/A
	Lamp & Ballast Replacement	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	103.34	75.08	154.54	2.08	3.3
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	105.69	71.06	152.88	3.74	3.2
Event III: New Construction and Renovation	Baseline	Baseline	27.8	27.8 W T5 & 0.67 BF Prog	102.27	81.02	158.61	N/A	N/A
	New Lamp & Ballast Purchase	EL 1	27.8	27.8 W T5 & 0.61 BF Prog	106.13	75.08	156.54	2.08	3.3
		EL 2	27.8	27.8 W T5 & 0.57 BF Prog	108.49	71.06	154.88	3.74	3.2

8B.8 INCANDESCENT REFLECTOR LAMP RESULTS

DOE analyzed IRLs that are standard spectrum, have voltages less than 125 V and diameters greater than 2.5 inches. DOE analyzed two representative lamp units at EL 1 in the commercial and residential sectors: a 55 W PAR38 halogen infrared (HIR) lamp with a lifetime of 2,500 hours and a 55 W PAR38 improved HIR lamp with a lifetime of 4,200 hours. DOE conducted both probability analyses (based on Monte Carlo runs) and scenario analyses for the IRLs analyzed.

8B.8.1 Monte Carlo Results

To characterize the LCC savings and Monte Carlo results for IRLs, DOE developed tables to describe the results distributions. These tables document the average LCC savings and percentages of buildings analyzed with positive and negative LCC savings for each lamp design. In addition, DOE reports the median and average payback period for every lamp design and EL. The following tables present the LCC savings and PBP Monte Carlo results for the IRLs analyzed operating in the commercial and residential sectors. Key inputs consist of using the *AEO 2013* reference case electricity prices and average-weighted lamp prices.

Table 8B.8.1 LCC and PBP Monte Carlo Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
									Net Cost	Net Benefit		
			lm/W		2012\$	2012\$	2012\$	2012\$			years	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.53	9.12	19.64	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	13.07	8.36	16.20	3.44	0.0	100.0	3.3	3.5

Table 8B.8.2 LCC and PBP Monte Carlo Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	years	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.39	10.39	19.78	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.93	9.53	17.13	2.65	0.0	100.0	5.5	5.7

Table 8B.8.3 LCC and PBP Monte Carlo Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	years	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.53	9.12	19.64	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	14.94	8.36	13.69	5.95	0.0	100.0	5.7	6.0

Table 8B.8.4 LCC and PBP Monte Carlo Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings			Mean Payback Period	Median Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	Percentage of Consumers that Experience			
			lm/W		2012\$	2012\$	2012\$	2012\$	Net Cost	Net Benefit	years	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.39	10.39	19.78	N/A	N/A	N/A	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.80	9.53	15.29	4.49	0.0	100.0	9.6	9.9

8B.8.2 Lamp Price Scenario Results

As mentioned earlier, DOE also analyzed LCC savings and PBP results using a scenario analysis. Because the LCC and PBP results are highly dependent on product prices, DOE examined sensitivities to the medium lamp price results presented in chapter 8 of this NOPR TSD by considering the low and high prices developed for IRLs in chapter 7 of this NOPR TSD. The following tables present the LCC savings and PBP results for the IRLs analyzed operating in the commercial and residential sectors, considering high and low lamp prices. Key inputs consist of using *AEO 2013* reference case electricity prices and average operating hours in each sector.

Table 8B.8.5 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	14.31	9.06	23.37	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	17.90	8.30	19.04	4.33	4.5

Table 8B.8.6 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	7.27	9.06	16.33	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	8.94	8.30	13.67	2.66	2.1

Table 8B.8.7 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector with High Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	13.18	10.36	23.54	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	16.77	9.49	20.18	3.35	7.6

Table 8B.8.8 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector with Low Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	6.14	10.36	16.50	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	7.81	9.49	14.47	2.02	3.5

Table 8B.8.9 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector with High Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	14.31	9.06	23.37	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	20.54	8.30	15.64	7.73	7.9

Table 8B.8.10 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector with Low Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	7.27	9.06	16.33	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	10.16	8.30	11.93	4.39	3.7

Table 8B.8.11 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector with High Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	13.18	10.36	23.54	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	19.41	9.49	17.60	5.94	13.2

Table 8B.8.12 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector with Low Lamp Prices

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	6.14	10.36	16.50	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	9.03	9.49	13.27	3.23	6.1

8B.8.3 Operating Hour Scenario Results

Monte Carlo results take into account distributions in operating hours across building types. However, because the LCC and PBP results are highly dependent on operating hours, DOE also examined sensitivities for operating hours. In the residential sector, because there is a large range of hours across room types (not depicted in the operating hour distribution over building types), DOE analyzed high operating hours (986 hours/year: the average operating hours of a lamp placed in the exterior of a single-family attached or multifamily home) and low operating hours (329 hours/year: the average operating hours of a lamp placed in a location in the other/unknown category of a multifamily or mobile home). These operating hours were obtained from the 2010 U.S. Lighting Market Characterization.² Other key inputs include *AEO 2013* reference case electricity prices and average-weighted lamp prices. The following tables present the LCC savings and PBP results for IRLs analyzed in the residential sector operating at high and low operating-hour scenarios.

Table 8B.8.13 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector using High Operating Hours

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.43	19.83	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	9.56	17.17	2.65	4.2

Table 8B.8.14 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector using Low Operating Hours

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	9.71	19.10	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	8.90	17.09	2.01	12.5

Table 8B.8.15 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector using High Operating Hours

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.43	19.83	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	9.56	15.33	4.50	7.2

Table 8B.8.16 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector using Low Operating Hours

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	9.71	19.10	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	8.90	15.74	3.36	21.7

8B.8.4 Electricity Price Trend Case Results

Because the LCC and PBP results for IRLs are also highly dependent on electricity prices, DOE examined the impacts of the *AEO 2013* high and low growth electricity price trend cases. Chapter 8 of this NOPR TSD describes the two cases and compares them with the *AEO 2013* reference case electricity price trend. The following tables present the LCC savings and PBP results for IRLs analyzed in the high and low growth cases. Key inputs consist of using average-weighted lamp prices and average operating hours in each sector.

Table 8B.8.17 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.20	19.72	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	13.07	8.43	16.27	3.45	3.2

Table 8B.8.18 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.24	19.77	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	13.07	8.47	16.31	3.45	3.1

Table 8B.8.19 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.40	19.80	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	9.53	17.15	2.65	5.4

Table 8B.8.20 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.64	20.03	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	9.75	17.36	2.67	5.2

Table 8B.8.21 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.20	19.72	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	14.94	8.43	13.77	5.96	5.5

Table 8B.8.22 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.24	19.77	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	14.94	8.47	13.81	5.96	5.5

Table 8B.8.23 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector under the AEO 2013 High Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.40	19.80	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	9.53	15.30	4.50	9.3

Table 8B.8.24 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector under the AEO 2013 Low Growth Electricity Price Trend Case

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.64	20.03	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	9.75	15.52	4.52	9.1

8B.8.5 All Dimmers Scenario Results

In the All Dimmers scenario, DOE modeled the impacts of individual lamps operated on dimmers. In this scenario, DOE assumed consumers will use this dimmer to equalize lumens of higher efficacy lamps to that of the baseline lamp. (See appendix 6A of this NOPR TSD for an assessment of the performance characteristics and annual energy consumption for this IRL dimming scenario.) The following tables present the LCC savings and PBP results for this dimming scenario.

Table 8B.8.25 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector, All Dimmers Scenario

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	28.27	38.80	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	13.07	27.54	40.02	-1.22	4.2

Table 8B.8.26 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector, All Dimmers Scenario

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	28.52	37.91	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	11.94	27.77	39.33	-1.42	21.5

Table 8B.8.27 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector, All Dimmers Scenario

Event	Response	Efficacy Level	Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	28.27	38.80	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	14.94	25.92	31.71	7.08	2.3

Table 8B.8.28 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector, All Dimmers Scenario

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period years
					Installed Cost 2012\$	Discounted Operating Cost 2012\$	LCC 2012\$	LCC Savings 2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	28.52	37.91	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	13.81	26.14	34.16	3.75	11.7

8B.8.6 Distribution of Dimmers With Lumens Equalized Results

In the Distribution of Dimmers scenario, DOE evaluated the effect of dimmers distributed across the population of consumers. In this scenario, DOE assumed consumers will use the dimmer to equalize the lumen output of higher efficacy lamps to that of the baseline lamp. (See appendix 6A of this NOPR TSD for the determination of percent of consumers that use dimmers and annual energy consumption impacts.) The following tables present the LCC savings and PBP results for this dimming scenario.

Table 8B.8.29 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector, Distribution of Dimmers Scenario With Lumens Equalized

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	3.21	3.3

Table 8B.8.30 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector, Distribution of Dimmers Scenario With Lumens Equalized

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	1.47	10.1

Table 8B.8.31 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector, Distribution of Dimmers Scenario With Lumens Equalized

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	6.00	5.4

Table 8B.8.32 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector, Distribution of Dimmers Scenario With Lumens Equalized

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	4.28	10.0

8B.8.7 Distribution of Dimmers Scenario With Lumens Reduced by Same Percentage Results

As noted for the Distribution of Dimmers scenario, DOE analyzed the case in which consumers dim to equalize lumens of higher efficacy lamps to that of the baseline lamp. Additionally, for this scenario DOE also evaluated an alternative assumption that

consumers who have higher efficacy lamps with dimmers do not maintain the lumen output of the baseline lamp but instead reduce the lumen output of the higher efficacy lamp by the same percentage lumen reduction that occurs for lamps at the baseline. (See appendix 6A of this NOPR TSD for an assessment of the annual energy consumption for this IRL dimming scenario.) The following tables present the LCC savings and PBP results for this dimming scenario.

Table 8B.8.33 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Commercial Sector with a Distribution of Dimmers Scenario with Lumens Reduced by Same Percentage

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	3.51	3.1

Table 8B.8.34 LCC and PBP Results for a 55 W PAR38 2,500 Hour HIR Lamp Operating in the Residential Sector with a Distribution of Dimmers Scenario with Lumens Reduced by Same Percentage

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 2500hrs, HIR	2.78	5.8

Table 8B.8.35 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Commercial Sector with a Distribution of Dimmers Scenario with Lumens Reduced by Same Percentage

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	6.00	5.4

Table 8B.8.36 LCC and PBP Results for a 55 W PAR38 4,200 Hour Improved HIR Lamp Operating in the Residential Sector with a Distribution of Dimmers Scenario with Lumens Reduced by Same Percentage

Event	Response	Efficacy Level	Efficacy lm/W	Lamp Option	Life Cycle Cost Savings 2012\$	Mean Payback Period years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.5	55W, 4200hrs, Improved HIR	4.28	10.0

8B.8.8 Shortened Lifetime Results

As discussed in chapters 5 and 9 of this NOPR TSD, DOE determined performance characteristics and prices for model lamps that meet EL 1 by shortening lifetime rather than using more efficient design options. Table 8B.8.37 shows the characteristics of the EL 1 lamp with a shortened lifetime relative to the baseline lamp.

Table 8B.8.37 Modeled EL 1 Characteristics of a 60 W PAR38 1,500 Hour Improved Halogen Lamp Operating with a Shortened Lifetime

Efficacy Level	Design Option	Lamp Descriptor	Wattage W	Efficacy lm/W	Initial Light Output lm	Lamp Life hr
Baseline	Improved Halogen	PAR38	60	17.8	1,070	1,500
EL 1	Improved Halogen	PAR38	60	18.7	1,124	1,046

The following tables show the LCC savings and PBP results for the shortened lifetime scenarios. Key inputs consist of using medium lamp prices and average operating hours in each sector.

Table 8B.8.38 LCC and PBP Results for a 60 W PAR38 1,500 Hour Improved Halogen Lamp Operating in the Commercial Sector with a Shortened Lifetime

Event	Response	Efficacy Level	Rated Lamp Efficacy lm/W	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
					2012\$	2012\$	2012\$	2012\$	
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	10.52	9.06	19.58	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.7	60W, 1046hrs, Improved Halogen	21.05	9.06	24.15	-4.57	NER

Table 8B.8.39 LCC and PBP Results for a 60 W PAR38 1,500 Hour Improved Halogen Lamp Operating in the Residential Sector with a Shortened Lifetime

Event	Response	Efficacy Level	Rated Lamp Efficacy	Lamp Option	Life Cycle Cost			Life Cycle Cost Savings	Mean Payback Period
					Installed Cost	Discounted Operating Cost	LCC	LCC Savings	
			lm/W		2012\$	2012\$	2012\$	2012\$	years
Event I: Lamp Failure; or Event III: New Construction and Renovation	Baseline	Baseline	17.8	60W, 1500hrs, Improved Halogen	9.40	10.36	19.75	N/A	N/A
	Lamp Replacement or New Lamp Purchase	EL 1	18.7	60W, 1046hrs, Improved Halogen	18.33	10.36	23.87	-4.12	NER

REFERENCES

¹ U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: 2010 U.S. Lighting Market Characterization. 2012. Washington, D.C.

< <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>>

² U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: 2010 U.S. Lighting Market Characterization. 2012. Washington, D.C.

< <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>>

APPENDIX 8C. RESIDENTIAL DISCOUNT RATE DISTRIBUTIONS

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APPENDIX 8C. HOUSEHOLD DISCOUNT RATE DISTRIBUTIONS

8C.1 INTRODUCTION

As discussed in chapter 8 of this NOPR (notice of proposed rulemaking) technical support document (TSD), the U.S. Department of Energy (DOE) characterized real interest rates associated with household debt and assets with probability distributions to develop a residential discount rate. The sections below provide the probability distributions.

8C.2 DISTRIBUTION OF REAL INTEREST RATES FOR CONSUMER DEBT CLASSES

Table 8C.2.1 presents weighted distributions of the real effective interest rates for various household debt classes. As reported in chapter 8 of this NOPR TSD, DOE used data from the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010 to generate the probability distributions for household debt. The weights associated with each binned rate correspond to the share of each value among the surveyed households. The bins correspond to all consumers who report a rate between two of the discrete levels in Table 8C.2.1 (*i.e.*, the 0.0 bin represents all consumers with a rate between 0.0 and 0.5). DOE calculated the rates shown in Table 8C.2.1 by developing a similar table from each of the eight *SCF* surveys. DOE used the average value in each binned rate and then averaged across the eight *SCF* surveys to derive the values shown in Table 8C.2.1.

Table 8C.2.1 Household Debt: Real Interest Rate Distributions

Home Equity		Credit Card		Installment Loans		Other Residence		Other Line of Credit	
Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)
0.0	5.3	0.0	5.7	0.0	36.7	0.0	1.6	0.0	3.5
0.5	8.6	0.5	1.1	0.5	1.6	0.5	2.1	0.5	3.7
1.5	10.2	1.5	1.6	1.5	2.4	1.5	6.7	1.5	3.5
2.5	11.8	2.5	2.3	2.5	4.3	2.5	15.5	2.5	5.6
3.5	20.8	3.5	3.2	3.5	3.5	3.5	18.5	3.5	5.2
4.5	21.4	4.5	4.4	4.5	4.4	4.5	19.2	4.5	11.6
5.5	14.0	5.5	5.9	5.5	5.2	5.5	16.1	5.5	10.7
6.5	3.4	6.5	6.5	6.5	6.4	6.5	10.4	6.5	8.3
7.5	2.5	7.5	3.2	7.5	2.6	7.5	4.3	7.5	4.8
8.5	0.3	8.5	6.6	8.5	3.6	8.5	2.8	8.5	10.1
9.5	0.7	9.5	5.9	9.5	2.5	9.5	0.8	9.5	6.4
10.5	0.0	10.5	5.7	10.5	3.2	10.5	0.4	10.5	4.5
11.5	0.2	11.5	5.7	11.5	1.3	11.5	0.4	11.5	5.6
12.5	0.2	12.5	4.5	12.5	2.2	12.5	0.3	12.5	3.9
13.5	0.2	13.5	4.6	13.5	1.6	13.5	0.1	13.5	1.4
14.5	0.2	14.5	11.6	14.5	4.7	14.5	0.3	14.5	4.1
15.5	0.1	15.5	8.4	15.5	2.8	15.5	0.2	15.5	2.5
16.5	0.0	16.5	3.3	16.5	1.8	16.5	0.1	16.5	1.0
17.5	0.0	17.5	3.9	17.5	2.2	17.5	0.1	17.5	0.4
		18.5	2.0	18.5	1.5	18.5	0.0	18.5	1.1
		19.5	1.2	19.5	1.2	19.5	0.0	19.5	0.6
		20.5	0.8	20.5	1.0	20.5	0.0	20.5	0.5
		21.5	0.5	21.5	1.1	21.5	0.0	21.5	0.6
		22.5	0.3	22.5	0.4	22.5	0.0	22.5	0.3
		23.5	0.2	23.5	0.1			23.5	0.0
		24.5	0.4	24.5	0.8			24.5	0.1
		25.5	0.3	25.5	0.0				
		26.5	0.0	26.5	0.0				
		27.5	0.0	27.5	0.0				
		28.5	0.0	28.5	0.1				
		29.5	0.0	29.5	0.0				
		30.5	0.0	30.5	0.0				
		31.5	0.0	31.5	0.0				
		32.5	0.0	32.5	0.0				
		33.5	0.0	33.5	0.0				
		34.5	0.0	34.5	0.0				
		35.5	0.0	35.5	0.1				
		36.5	0.0	36.5	0.0				
				37.5	0.0				
				38.5	0.0				
				39.5	0.5				

8C.3 DISTRIBUTION OF REAL INTEREST RATES FOR FINANCIAL ASSETS

Table 8C.3.1 presents the time series of real effective interest rates associated with various household asset types. As reported in chapter 8 of this NOPR TSD, DOE used data from the various sources to generate the probability distributions for each of the asset types identified in Table 8C.3.1. For each asset, the average, minimum, maximum, and standard deviation are provided. DOE developed probability distributions based on the average value and standard deviation. Because the use of the standard deviations yields distributions with negative values, DOE truncated the lower end of the normal distribution at a discount rate of zero. DOE also truncated the higher end of the normal distribution in equal proportion to the truncation at the lower end to maintain the average values above in Table 8C.3.1.

Table 8C.3.1 Household Assets: Time Series of Real Interest Rates

Year	Savings Accounts (%)	CDs 6 Months (%)	Treasury Savings Bonds (%)	Corp AAA Bonds (%)	Stocks S&P 500 (%)	Mutual Funds (%)
1983	-	5.9	8.3	8.6	18.5	15.2
1984	5.5	6.1	7.9	8.0	1.8	3.9
1985	5.3	4.5	7.5	7.5	26.7	20.3
1986	6.0	4.6	7.1	7.0	16.3	13.2
1987	3.3	3.2	5.7	5.5	2.1	3.2
1988	3.1	3.6	5.2	5.4	11.9	9.7
1989	3.0	4.1	4.0	4.2	25.4	18.4
1990	2.4	2.6	3.5	3.7	-8.0	-4.1
1991	2.7	1.6	4.2	4.4	25.0	18.1
1992	2.1	0.7	4.9	5.0	4.4	4.6
1993	1.1	0.3	3.9	4.1	6.8	5.9
1994	1.3	2.3	5.0	5.3	-1.2	1.0
1995	2.2	3.1	4.5	4.6	33.4	23.8
1996	2.0	2.4	4.2	4.3	19.2	14.2
1997	2.7	3.4	4.6	4.9	30.1	21.7
1998	3.4	3.8	4.8	4.9	26.4	19.2
1999	2.3	3.2	4.5	4.7	18.3	13.8
2000	1.7	3.1	3.7	4.1	-12.0	-6.6
2001	1.8	0.8	3.5	4.1	-14.3	-8.2
2002	1.3	0.2	4.6	4.8	-23.2	-13.8
2003	-0.2	-1.1	3.4	3.3	25.5	18.1
2004	-0.7	-0.9	3.0	2.9	7.9	6.2
2005	-0.2	0.3	1.9	1.8	1.4	1.5
2006	1.1	2.0	2.1	2.3	12.0	8.8
2007	2.0	2.3	2.5	2.6	2.6	2.6
2008	0.2	-0.7	2.0	1.7	-38.9	-25.4
2009	3.6	1.2	6.0	5.7	26.4	19.5
2010	0.6	-1.2	3.5	3.2	13.0	9.7
2011	-1.0	-2.7	2.2	1.4	-1.1	-0.2
2012	-0.1	-1.6	2.4	1.6	13.5	9.5
Average	2.0	1.9	4.3	4.4	7.6	6.8
Minimum	-1.0	-2.7	1.9	1.4	-38.9	-25.4
Maximum	6.0	6.1	8.3	8.6	33.4	23.8
Std. Dev.	1.8	2.2	1.7	1.8	16.8	11.4

APPENDIX 8D. HOT SHOCK IN INCANDESCENT REFLECTOR LAMPS

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APPENDIX 8D. HOT SHOCK IN INCANDESCENT REFLECTOR LAMPS

8D.1 INTRODUCTION AND PURPOSE

Incandescent reflector lamps (IRLs) produce light when a thin tungsten wire (filament) inside the lamp is heated to a temperature high enough to cause *incandescence*, which is the production of electromagnetic energy in the visible spectrum due to the movement of high-temperature molecules. IRLs that feature halogen or halogen infrared (HIR) technologies incorporate a filament that is contained within a small capsule inside of the lamp. In order for the filament to fit inside of the capsule while being of the necessary length to allow the lamp to obtain its rated performance, the filament must be coiled upon itself.

Because the filament is thin, it is subject to movement due to forces (such as sudden jolts) applied to the lamp. The coiled structure of the filament brings it in close proximity with other parts of itself and external forces to the lamp can cause parts of the filament to touch each other. If this self-contact occurs when the filament is heated and producing light, the areas that contact each other can weld together and cause an electrical short. Electrical current is higher through a shorted circuit and produces a higher temperature that subsequently reduces the life of the lamp. This phenomenon is known as *hot shock*. Figure 8D.1.1 shows an image of a filament that has experienced hot shock; the darkened regions are where the coils have been shorted. While certain kinds of IRLs contain filament supports to reduce the probability of hot shock, halogen and HIR capsules do not contain such supports because they would reduce lamp efficacy.¹

Hot shock can occur when an IRL is installed into an electrical socket that is active, which causes electricity to flow through the lamp before it is completely seated by the installer.² Hot shock can also occur during the movement of active lamps. Thus, one way to avoid hot shock in IRLs is to deactivate the electrical socket during lamp installation or during lamp position adjustments on movable fixtures (such as movable spotlights). If the electrical connection cannot be deactivated, then the lamps should be installed or moved as smoothly and carefully as possible to reduce the risk of hot shock.

Because lamp lifetime impacts the life-cycle cost (LCC) analysis and hot shock shortens the lifetime of IRLs, the U.S. Department of Energy (DOE) evaluated the possible impacts of hot shock on potential standards.



Figure 8D.1.1 Filament after Hot Shock; Shorted Coils Visible³

8D.2 IMPACT OF STANDARDS

DOE analyzed the impacts of standards at the efficacy level (EL) proposed for IRLs with respect to shortened lifetime as a result of hot shock. Because the LCC of a product depends directly on the product lifetime, the occurrence of hot shock in an IRL will impact the LCC savings to the consumer. Switching to a more efficacious IRL that operates for a longer time will result in an increase in the residual value of the lamp, delivering greater LCC savings to the consumer. Therefore, DOE performed an analysis to determine how much the lifetime of IRLs at EL 1 could be shortened before there are no LCC savings.

As discussed in chapter 5 of this notice of proposed rulemaking (NOPR) technical support document (TSD), DOE evaluated two representative lamps at EL 1 for IRLs, a 2,500-hour HIR lamp and a 4,200-hour improved HIR lamp. To obtain minimum lifetime values, DOE reduced the lifetime of lamps at EL 1 for all scenarios with positive LCC savings until those savings reached zero. The results of this analysis are shown in Table 8D.2.1. IRL lifetime can be shortened by 30 percent in the commercial sector and 29 percent in the residential sector before the consumer does not achieve any LCC savings at EL 1 for the 2,500-hour HIR representative lamp. IRL lifetime can be shortened by 53 percent in the commercial sector and 50 percent in the residential sector before the consumer does not achieve any LCC savings at EL 1 for the 4,200-hour improved HIR representative lamp.

Table 8D.2.1 IRL Lifetime Reduction at EL 1

EL 1 Representative Lamp	Commercial Sector		Residential Sector	
	Lifetime (hours)	Percent Reduction	Lifetime (hours)	Percent Reduction
55 W PAR38 2,500 hour HIR	1,738	30%	1,776	29%
55 W PAR38 4,200 hour Improved HIR	1,987	53%	2,095	50%

REFERENCES

¹ GE Consumer & Industrial Lighting. 2009. No. 63, Appendix 5 at p. 1. This attachment to a written comment, Document Number 63 Appendix 5, is available in Docket #EE-2006-STD-0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

² GE Consumer & Industrial Lighting. 2009. No. 63, Appendix 5 at p. 1. This attachment to a written comment, Document Number 63 Appendix 5, is available in Docket #EE-2006-STD-0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

³ National Electrical Manufacturers Association. 2009. No. 81 at p. 27. This written comment, Document Number 81, is available in Docket #EE-2006-STD-0131. For more information, contact Brenda Edwards-Jones at (202) 586-2945.

APPENDIX 11A. LIGHTING CONTROLS MARKET PENETRATION PROJECTION

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11A.1 BACKGROUND

Lighting controls include a range of technologies to turn lights off or down when they are not needed or wanted. Of interest to this rulemaking are control technologies that go beyond manual on-off switching, which is almost universally included in lighting. These include manual dimmers, automatic timers, and sensor-based controls. Timers can be used to automatically adjust lighting based on occupancy schedules and daylight hours. More advanced sensor-based controls adjust light output based on signals received from the sensors. Occupancy sensors—often referred to as motion sensors for outdoor applications and vacancy sensors for indoor applications—include infrared, ultrasonic, and, to a far lesser extent, microwave sensors. Photosensors are used to adjust light output to account for background light levels, typically from daylight.

The purpose of this appendix is to describe the assumptions and analysis the U.S. Department of Energy (DOE) used to project changes in the penetration of lighting controls over the analysis period of this rulemaking. DOE incorporates lighting controls in the analysis, because they can indirectly affect lamp lifetimes and, therefore, shipments (chapter 11); controls also directly affect lamp energy use and, therefore, the national impact analysis (chapter 12). There are large, inherent uncertainties in the extent to which the penetration of specific controls technologies will change over time. The next section describes the approach DOE took to estimate the penetration of lighting controls technologies in the building stock for the shipments and NIA analysis for this rulemaking.

11A.2 APPROACH

DOE considered the impact of state building codes and other factors in estimating the adoption of lighting controls over the analysis period, as described in the following sections.

11A.2.1 The Impact of State Building Codes on Controls Penetration

Federal model energy codes drive the adoption and revision of state building codes. DOE adopts different model codes for commercial and residential buildings. ASHRAE Standard 90.1 is the model energy code for commercial and multi-family high-rise residential buildings. The International Energy Conservation Code (IECC) is the model energy code for low-rise residential buildings. Both include provisions on lighting and are updated periodically. The Energy Conservation and Production Act (ECPA), as amended, requires that DOE, within one year of revision of either document, issue a determination as to whether the revised edition will improve energy efficiency compared to previous editions.¹ If DOE finds that the newest version of ASHRAE 90.1 is more energy efficient than the previous version, states are required by the Energy Policy Act of 1992 (EPACT 1992) to certify that their building energy codes or standards meet or exceed the requirements of the new standard within two years. If the analysis shows that the revised IECC is more energy efficient than the previous edition, EPACT 1992 requires states to certify that they have reviewed their residential building energy codes regarding energy efficiency and made a decision as to whether it is appropriate for that state to revise its residential building code to meet or exceed the revised code.²

Therefore, state compliance with the model codes is compulsory for commercial buildings, but not for residential buildings. DOE therefore treated the two sectors different in this analysis. For the residential sector, DOE assumed that the use of lighting controls remains constant at today's level. DOE seeks input from stakeholders on the validity of this assumption.

To project the future penetration of commercial lighting controls, DOE assumed that state building code requirements remain as they are today, with controls being installed as required for new construction and renovation. The current model energy code for commercial buildings, ASHRAE 90.1-2007, section 9.4.1.1, mandates that almost all interior lighting be controlled either by a timer, an occupancy sensor, or a signal from a separate system. Exceptions are made for buildings that are less than 5,000 square feet in floor area and for health and safety; hospital operating rooms and spaces that specifically require 24-hour lighting. In the current building stock, the square footage covered by these exceptions totals 9% of commercial floor space. Most of that is exempted because the floor area is less than 5,000 square feet. However, DOE has determined that ASHRAE 90.1-2010 will yield significant additional savings, so it will become the new model code. The 2010 code eliminates the exception for commercial buildings less than 5,000 square feet, with the result that an estimated 98% of total commercial floor space would be required to include lighting controls—essentially all viable floor area. DOE does not model the adoption of the 2010 code in this rulemaking because it is uncertain if and when states will adopt the code.

In addition to the mandatory general lighting provisions of section 9.4.1.1 described previously, ASHRAE 90.1-2007 includes additional requirements for lighting controls in some smaller spaces, such as individual offices, which may be superimposed on controls required under the general provisions. DOE did not attempt to account for the effect of multiple layers of controls or improvements in control technologies that may take place over time. This appendix calculates only the lighting capacity (in teralumens) covered by controls. Given the lack of data on whether multiple levels of controls would be adopted and which controls will be adopted in which areas, the energy use calculations in chapter 12 assume that controls yield a fixed 30% energy savings if controls are required for the floor area.³

Compliance rates are the largest source of uncertainty in the analysis. Given that all of the most populous states are currently compliant with the federal requirement to adopt the model code or better, future changes in the level of state compliance should do little to change the results of the energy analysis. The level of builders' compliance with state codes is less clear. This analysis assumes a 75 percent overall compliance rate.

Using the assumptions described above, DOE estimated the national commercial lighting capacity (in teralumens) covered by lighting controls for each year of the analysis, based on the floor space projected to be operating under lighting controls, using a computational model developed by Sturges (2012).⁴ The model estimates the commercial floor area incorporating controls, accounting for the current variation in standards adopted by the states, the relevant floor area in each state, the breakdown of floor area by application, and the code requirements for each floor area application. Because the analysis period in Sturges' study extended only until 2030, for this rulemaking DOE extrapolated Sturges' projection to the end of the analysis period (2046). The results of the analysis are described in section 11A.3.

11A.2.2 The Impact of Other Factors on Controls Penetration

In addition to lighting controls installed as a result of state building codes, some fraction of building owners install controls for other reasons. For the commercial sector, DOE computed the current lighting capacity installed for other reasons from the difference between the current total lighting capacity under controls and the lighting capacity under controls as a result of building codes, based on Sturges' model. DOE's 2010 Lighting Market Characterization (LMC) estimates that 30% of commercial lighting was governed by lighting controls in 2010.⁵ The building codes analysis estimated that state codes would have resulted in only 12% of floorspace having implemented lighting controls at the beginning of the analysis period. Assuming that floorspace fractions equate approximately to lighting fractions, an estimated 18% of commercial lighting is assumed to be using lighting controls for other reasons. DOE held that fraction fixed throughout the analysis period.

11A.3 RESULTS AND CONCLUSIONS

Figure 11A.3.1 shows DOE's projection of the teralumen hours of capacity expected to be operating under controls as a result of building codes, and for other reasons. Total lumen capacity is also included in the plot for comparison. As shown, by the end of the analysis period approximately 75% of commercial floor space is expected to be operating under lighting controls, assuming that today's building codes remain frozen in place and a 75 percent compliance rate. If ASHRAE 90.1-2010 is adopted by the states, there will be some increase in lumen capacity covered by controls, because the lighting controls exception for small buildings will be eliminated. The magnitude of that increase will depend on which states adopt the standard and when. However, a larger uncertainty appears to be the rate at which builders comply with state code requirements. Currently, DOE is assuming a 75% compliance rate.

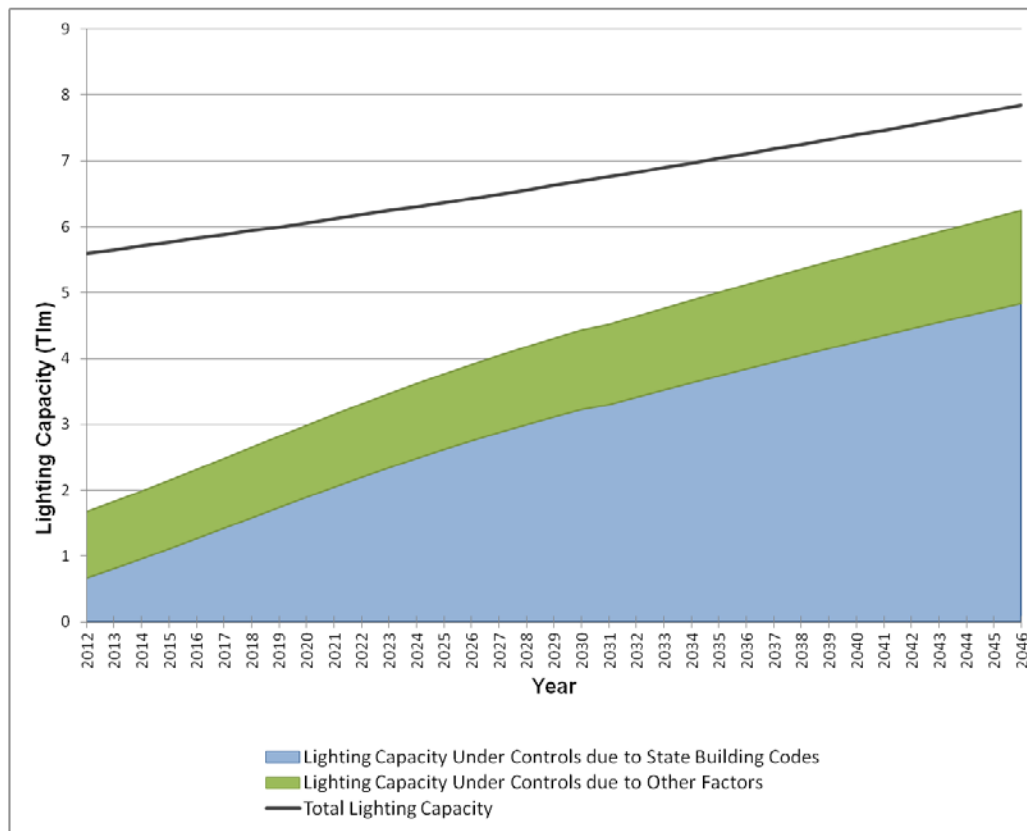


Figure 11A.3.1 U.S. Total Annual Commercial Lighting Capacity and the Capacity Projected to be Operating under Lighting Controls

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- ² <http://www.energycodes.gov/regulations/determinations>
- ³ Williams, A., B. Atkinson, K. Garbesi, E. Page, and F. Rubinstein (2012). Lighting controls in commercial buildings. *Leukos* 8(3): 161-180.
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- ⁴ Sturges, A, "Modeling the Market Penetration of Advanced Lighting Controls in the U.S Commercial Sector" (master's thesis, Duke University, Nicholas School of the Environment, 2012). Available online at <http://dukespace.lib.duke.edu/dspace/handle/10161/5278>
- ⁵ U.S. Department of Energy- Energy Efficiency & Renewable Energy Building Technologies Program. *2010 U.S. Lighting Market Characterization*. January 2012. Washington, D.C.
<http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf>

APPENDIX 11B. MODELING OF RARE EARTH PRICE IMPACTS

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11B.1 BACKGROUND

Lamp manufacturers use triband phosphors to increase the efficacy of fluorescent lamps and improve their color quality and lumen maintenance. All GSFLs that meet current efficiency standards use triband phosphors. Triband phosphors contain certain rare earth elements - lanthanum (La), cerium (Ce), europium (Eu), terbium (Tb), and yttrium (Y) - which, according to manufacturer interviews provided to the U.S. Department of Energy (DOE), are generally purchased by lamp manufacturers in their oxide form. Between the second quarter of 2010 and the fourth quarter of 2011, the price of rare earth oxides (REOs) increased sharply, causing concerns about the resulting price impacts on fluorescent lamps. However, as shown in Figure 11B.1.1, REO¹ prices have recently fallen considerably.

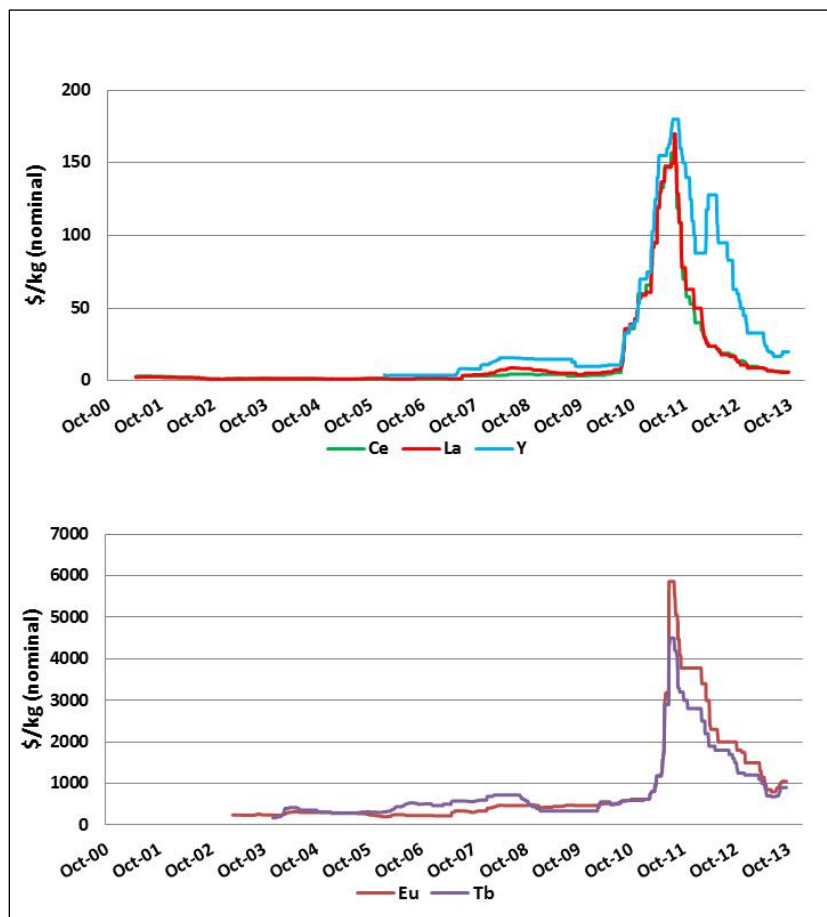


Figure 11B.1.1 Rare Earth Oxide Historic Prices^a

NEMA also commented that, according to Dr. Alan King of the Critical Materials Institute of the AMES Laboratories, once a material becomes critical, it tends to stay critical—that is, it continues to undergo price fluctuations. Accordingly, NEMA recommended that DOE consult King on the issue. DOE did confer with King, who indicated that a good comparison can

^a The reported oxide prices correspond to 99% purity minimum Free-on-Board (FOB) China for Ce, La, and Tb, 99.9% purity minimum FOB China for Eu, and 99.999% purity minimum FOB China for Y.

be made between rare earths and cobalt, which are comparable (within about a factor of ten) in abundance in the earth's crust. In 1978, world cobalt supplies were dominated by a single source (Zaire). In 2010, rare earth supplies were dominated by a single source (China). In 1978, the use of cobalt was growing both in existing and emerging technologies. The same is true for rare earths today. Following the 1978 crisis, new cobalt mines opened and substitute materials were developed. Markets are pursuing the same paths for the rare earths today. DOE examined inflation adjusted cobalt prices from 1970 through 2012² and found that cobalt prices did continue to remain volatile; although, as shown in Figure 11B.1.2, later price fluctuations were less than half of the initial price peak seen in 1978.

DOE incorporates the potential impact of higher rare earth prices and price volatility in a scenario of the shipments analysis. The model assumes a high rare earth price that is midway between the 2011 peak price and the pre-peak baseline price. For cobalt, after the initial peak, only the highest points of some subsequent peaks meet a midpoint value. Therefore, the best available data suggest that future rare-earth prices are unlikely to maintain an average value that exceeds DOE's high estimate.

This appendix describes the approach DOE took to projecting the potential impacts of volatile rare earth prices on lamp shipments, energy savings, and net present value of trial standard levels considered in this NOPR TSD.

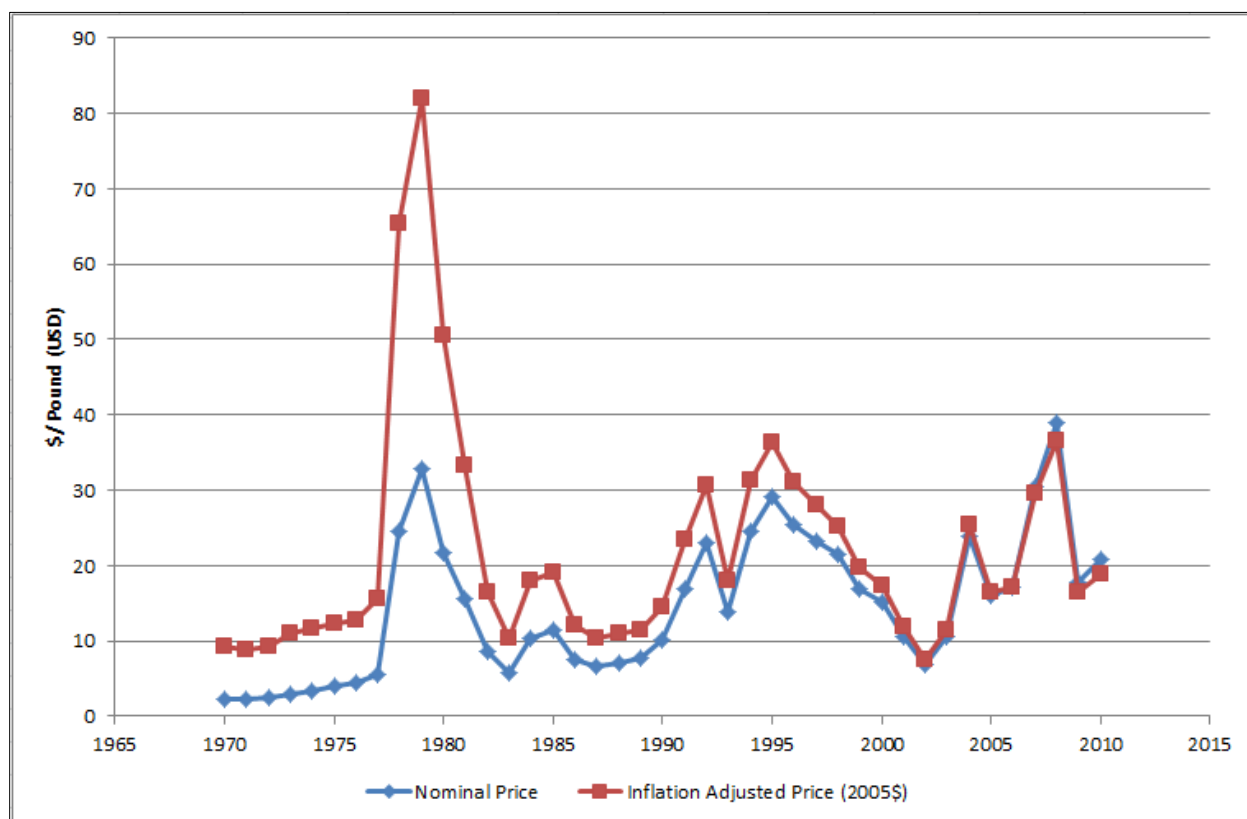


Figure 11B.1.2 Historic Cobalt Prices

11B.2 ANALYSIS

DOE analyzed the impact of REO prices on GSFL costs based on historical prices of REOs (Figure 11B.1.1) and on estimates of the average rare earth element content in phosphors of high efficacy T5 and T8 lamps, as reported in DOE's 2011 Critical Materials Strategy (CMS).³ The 2011 CMS estimated the content of rare earth elements in fluorescent lamp phosphors based on manufacturer interviews and lamps' properties. According to the report, 800-series lamps use 100 percent triband phosphor, whereas 700-series lamps use approximately 30 percent triband phosphor.

According to the 2011 CMS, the amount of phosphor included in fluorescent lamps is approximately proportional to the surface area of the lamps. Therefore, T8 lamps on average contain about 1.6 times more phosphor than T5 lamps of the same efficacy, and 8-foot T8 lamps contain twice as much phosphor as do 4-foot T8 lamps of the same efficacy. Table 11B.2.1 shows the average mass content of rare earth elements in 800-series and 700-series T5 and T8 lamps, and the corresponding lamp surface area according to the 2011 CMS. For 800-series lamps, the rare earth mass content per unit area for each lamp type is approximately 2.4 milligrams per square centimeter of lamp tube surface area (mg/cm^2).

Table 11B.2.1 Average Mass Content, Surface Area and Mass Content of Rare Earth Elements in 800-series T5 and T8 Lamps

Lamp type	Rare Earth Content (grams)	Lamp Surface Area (cm^2)
4ft T8 – 800-series	2.334	972
4ft T8 – 700-series	0.700	
4ft T5 – 800-series	1.458	608
4ft T5 – 700-series	0.437	
8ft T8 – 800-series	4.668	1946
8ft T8 – 700-series	1.400	

Table 11B.2.2 shows the average percentage contribution of the five rare earth elements used in GSFL triband phosphors according to the 2011 CMS.

Table 11B.2.2 Average Rare Earth Element Mass Percentages used in GSFL Triband Phosphors

Element	Content
Lanthanum	22%
Cerium	6.5%
Europium	4.5%
Terbium	5%
Yttrium	62%
TOTAL	100%

For this rulemaking, using the data shown in Figure 11B.1.1, DOE calculated a triband phosphor price index for GSFLs that reflects the rare earth element mass percentages reported in Table 11B.2.2, and the corresponding rare earth oxide prices reported in metalpages.com.^b The index, shown in Figure 11B.2.1, is inflation adjusted and normalized with respect to the average triband phosphor cost between 2006 and 2009, the longest period prior to the peak for which data for all relevant REOs were available. As shown in the Figure, the index rose rapidly in 2010 from a relatively stable period to a peak in 2011, after which it dropped almost monotonically, to a point near its pre-peak level.

^b This analysis assumes that mass fractions of REOs needed for manufacturing are the same as the elemental mass fractions in Table 11B.2.2.

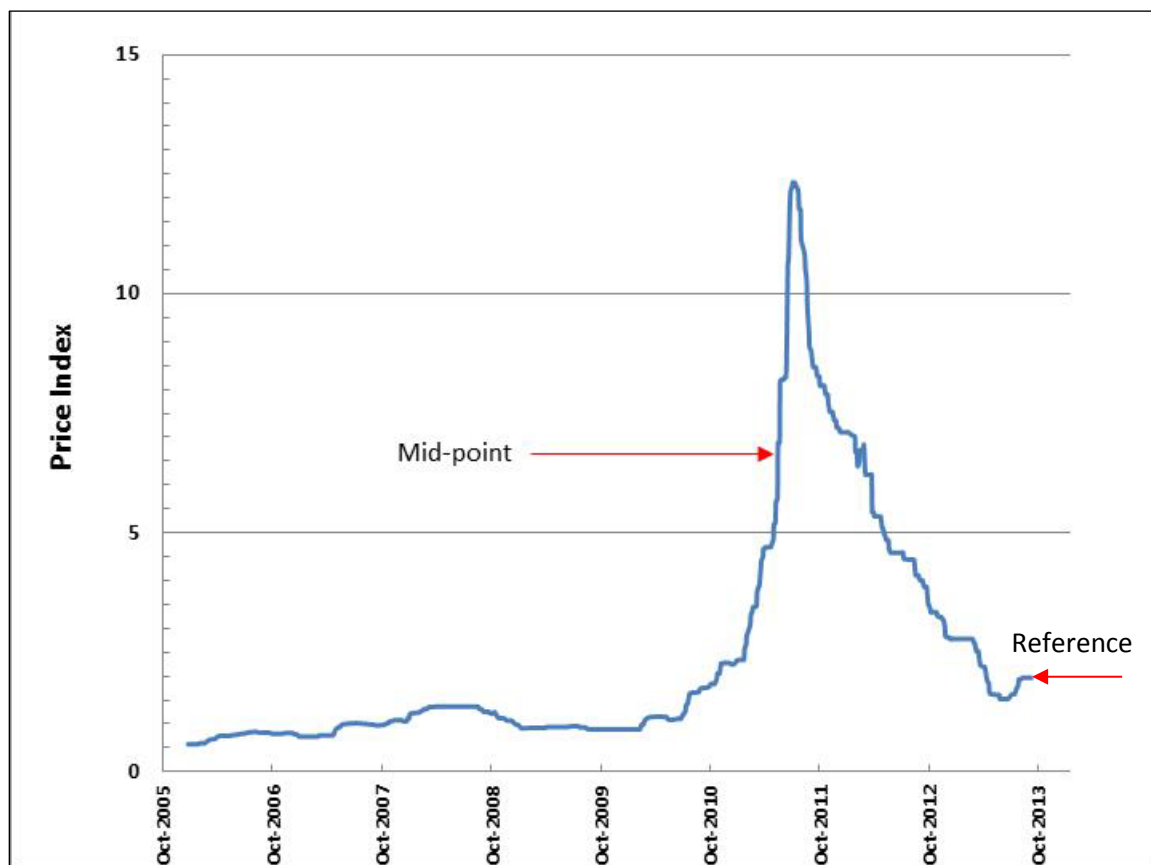


Figure 11B.2.1 Inflation-Adjusted, Triband Phosphor REO Price Index for GSFLs

The future trajectory of REO prices is highly uncertain. Therefore, DOE developed an alternative scenario for future REO prices for the shipments and national impact analyses. The reference assumption is that REO prices remain constant at their October 2013 level. These data were used in this NOPR TSD, because they represent the most recent price data available. The high REO price scenario uses the REO price midway between the 2011 peak and the 2006 – 2009 baseline average price, referred to here as the *mid-point REO price*.

Effect of Phosphor Content on Lamp Efficacy

In the preliminary analysis of this rulemaking DOE assumed that all covered GSFLs were now using the maximum practical REO content and that, for any given lamp type, lamp efficacy was independent of lamp REO content. DOE received comment from NEMA⁴ regarding the relationship between phosphor weight (mass) and lamp efficacy; NEMA indicated that for 4-foot medium bipin GSFLs, an efficacy increase from 89 lm/W (baseline) to 90 lm/W requires a 10% increase in phosphor mass, and an efficacy increase from 89 lm/W to 93 lm/W requires a 40% increase in phosphor mass. DOE's research indicates as the phosphor mass per unit area increases, lamp efficacy increases until it flattens out, or slightly decreases, as shown in Figure 11B.2.2).

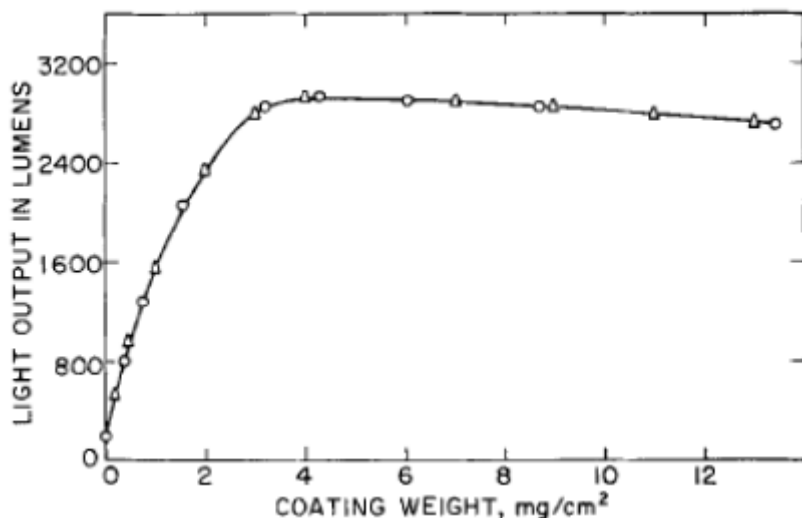


Figure 11B.2.2 Light Output versus Phosphor Coating Weight⁵

As discussed above, according to the 2011 CMS, 800-series GSFLs have a phosphor content (mass per unit area) of 2.4 mg/cm². Also, according to Figure 11B.2.2, GSFL efficacy increases up to about 3.3 mg/cm² of phosphor with no further efficacy gains beyond this point. DOE also examined more recent sources⁶ that confirmed these estimates. Therefore, DOE assumes that any additional phosphor content increase (above 3.3 mg/cm², which corresponds to a gain of about 40%) does not further raise lamp efficacy, and that any lamp efficacy improvements beyond this point are due to other design options.

For this NOPR TSD, DOE accounted for the REO content of lamps with different efficacies in the following way. DOE assumed that 700-series lamps contain 30% of the triband phosphor content relative to the basic 800-series representative unit (as defined in chapter 5 of this TSD). For 800-series lamps, using information received by NEMA, and assuming that 800-series GSFLs at their baseline efficacy levels have the phosphor contents specified in the 2011 CMS (2.4 mg/cm²), DOE developed a relationship between efficacy and phosphor content relative to the basic 800-series representative unit, according to the following equation:

$$Mass_{rel} = 8.9 \times Efficacy_{rel} - 7.9 \quad , if \text{ phosphor content } < 3.3 \frac{mg}{cm^2} \quad \text{Eq. 11B.1}$$

$$Mass_{rel} = 1.4 \quad , if \text{ phosphor content } \geq 3.3 \frac{mg}{cm^2} \quad \text{Eq. 11B.2}$$

Where:

$Mass_{rel}$: The REO mass, relative to its mass at the basic 800-series efficacy level

$Efficacy_{rel}$: The GSFL efficacy, relative to the its basic 800-series efficacy level

DOE used the average mass content and REO mass percentages in GSFLs from Table 11B.2.1 and Table 11B.2.2, respectively and applied Eq. 11B.1 and Eq. 11B.2 to determine the inflation adjusted (2011\$) reference scenario REO cost ($c_{REO,Ref}$) based on Oct. 3, 2013 REO

prices for each lamp option. The results are shown in Table 11B.2.3. These REO costs serve as a reference from which to account for the potential impacts of potential future higher REO prices.

Table 11B.2.3 Reference Scenario REO Costs

Lamp Type	Lamp Option ID*	Lamp Series #	Efficacy (rated [lm/W])	Relative Efficacy to Basic 800-series	REO Cost (\$2011)
4-foot Medium Bipin	L1.0.1	800	89.2	1.00	\$ 0.24
	L1.1.1	800	90.0	1.01	\$ 0.26
	L1.2.1	800	95.4	1.07	\$ 0.34
	L1.2.2	800	96.0	1.08	\$ 0.34
	L1.2.3	800	93.0	1.04	\$ 0.33
8-foot Slimline	L2.0.1	800**	96.5	N/A	\$ 0.14
	L2.1.1	800	98.2	1.00	\$ 0.48
	L2.2.1	800	99.0	1.01	\$ 0.52
	L2.2.2	800	105.6	1.08	\$ 0.67
	L2.2.3	800	108.0	1.10	\$ 0.67
8-foot HO	L3.0.1	N/A**	92.0	N/A	\$ 0.14
	L3.1.1	700	95.2	N/A	\$ 0.14
	L3.2.1	800	97.6	1.00	\$ 0.48
T5 SO	L4.0.1	N/A**	94.6	N/A	\$ 0.05
	L4.1.1	800	104.3	1.00	\$ 0.15
	L4.2.1	800	109.7	1.05	\$ 0.21
	L4.2.2	800	111.5	1.07	\$ 0.21
	L4.2.3	800	116.0	1.11	\$ 0.21
T5 HO	L5.0.1	N/A**	83.6	N/A	\$ 0.05
	L5.1.1	800	92.9	1.00	\$ 0.15
	L5.1.2	800	102.0	1.10	\$ 0.21
	L5.1.3	800	102.1	1.10	\$ 0.21

*Defined in Chapter 11, Shipments

**Assumed to use a similar REO content as 700-series lamps

Recognizing that REO costs are only one element of GSFL prices, which may have an independent trajectory, DOE accounts for REO costs and the balance of lamps costs independently.

The price of each GSFL, as a function of the REO cost, is expressed as follows:

$$p(y)_{GSFL} = m_r \times (c_{REO,scen} + c(y)_{else})$$

Eq. 11B.3

Where:

$p(y)_{GSFL}$ = lamp price at year y ,

m_r = markup of manufacturer cost to retail price: (estimated as 2.31, according to Chapter 13, Manufacturer Impact Analysis),

$c_{REO,scen}$ = REO cost for price scenario (reference, or mid-point), and
 $c(y)_{else}$ = Cost to manufacture lamp at year y , excluding $c_{REO,scen}$

DOE addresses price learning in its shipments and national impact analysis (NIA) calculations. However, because price learning is not applicable to raw materials inputs to manufacturing and, therefore, is not applicable to the REO part of lamps costs, Eq. 11B.3 was rewritten in the following way for use in the shipments and NIA models:

$$p(y)_{GSFL} = m_r \times \left(SM \times c_{REO,Ref} + PLF(y) \times \left(\frac{p_{GSFL,0}}{m_r} - c_{REO,Ref} \right) \right)$$

Eq. 11B.4

Where:

SM = scenario multiplier for REO cost scenarios (described below),
 $c_{REO,Ref}$ = reference scenario REO cost per GSFL (itemized below),
 $PLF(y)$ = price learning correction factor at year y (described below) and,
 $p_{GSFL,0}$ = 2012 ‘weighted average’ GSFL price.

The scenario multiplier (SM) is based on the triband phosphor price index, normalized to its reference scenario value. The reference and the mid-point scenario correspond to the price index of the mid-point REO price, and the index of the most recent REO price (October 2013), respectively:

- Mid-point $SM = 3.4$
- Reference scenario, $SM = 1$

The price learning correction factor (PLF) is defined as follows:

$$PLF(y) = \left(\frac{X(y)}{X(y_0)} \right)^{-b}$$

Eq. 11B.5

Where:

$X(y)$ = the cumulative production (total shipments) of GSFL between the year of introduction to the market to year y , as defined in Eq. 11.5,
 $X(y_0)$ = the cumulative production (total shipments) of GSFL between the year of introduction the market to the initial year of the forecasting period (2012), and
 b = the learning rate parameter, as defined in Eq. 11.4.

The ‘weighted average’ 2012 lamp price ($p_{GSFL,0}$) is derived from chapter 5, Engineering Analysis.

11B.3 CHANGE IN REO DEMAND OWING TO REVISED STANDARDS

To assess whether a revised standard on GSFLs would significantly change the demand for REOs, DOE estimated the change in demand of REO that would result from revised standards. To do this DOE calculated the change in shipments (see chapter 11 of this TSD) in the Reference Scenario, for each lamp type in the standards case compared to the base case and multiplied by the mass of REO contained in each lamp type, Eq. 11B.6. DOE estimated the mass of REOs used in the each lamp option by multiplying the REO content in Table 11B.2.1 by a scaling factor derived from Eq. 11B.1 and Eq. 11B.2. For lamp options that did not have a scaling factor, DOE used the REO content estimated for 700-series lamps of the same type. The results are presented in Table 11B.3.1 below. The global demand for REO used in phosphors in 2011 was estimated at 8000 tons.⁷ As can be seen in Table 11B.3.1, the annual increase in REO demand for all TSLs is small in comparison, amounting to less than 4% of global demand at its maximum. For TSL 5, the proposed TSL, the change in REO demand peaks in the first year of rule and decreases over the analysis period. Therefore, DOE concludes that revised efficiency standards for GSFLs will not cause a significant change in the demand of REOs.

$$\Delta \text{Mass}_{\text{REO}}(y) = C_{kg \text{ to tons}} \sum_i (s(y)_{i, \text{std}} - s(y)_{i, \text{base}}) * \text{Mass}_{\text{REO}, i}$$

Eq. 11B.6

Where

$\Delta \text{Mass}_{\text{REO}}(y)$ = change in mass of REO in year y (tons)

$C_{kg \text{ to tons}}$ = unit conversion factor (1.1×10^{-3} tons/kg)

$s(y)_{i, \text{std}}$ = shipments of lamp option i in year y in the standards case (number of units)

$s(y)_{i, \text{base}}$ = shipments of lamp option i in year y in the base case (number of units)

$\text{Mass}_{\text{REO}, i}$ = mass of REOs contained in lamp option i (kg)

Table 11B.3.1 Increase in REO demand caused by standards (tons/year)

	TSL 1	TSL 2	TSL 3	TSL 4	TSL 5
2017	38.7	60.7	108.3	232.9	296.4
2018	40.3	61.3	109.0	229.9	293.3
2019	41.4	61.5	108.3	225.9	289.6
2020	41.6	61.0	106.2	218.8	282.7
2021	41.1	59.0	102.7	206.9	270.4
2022	40.4	56.3	98.6	189.4	253.3
2023	39.8	53.8	94.2	166.6	233.2
2024	39.0	51.4	89.5	145.1	215.1

2025	37.9	49.0	85.4	131.0	203.3
2026	36.4	46.2	81.1	119.7	192.4
2027	35.1	43.6	76.8	106.1	178.8
2028	33.6	40.8	71.9	88.8	160.9
2029	32.1	38.1	66.8	71.4	142.4
2030	30.5	35.4	61.9	57.3	126.0
2031	29.0	33.1	57.6	46.8	113.0
2032	27.3	30.7	53.3	39.2	101.9
2033	25.4	28.3	49.2	33.2	91.9
2034	23.5	25.9	45.2	28.2	83.0
2035	21.3	23.4	41.0	23.7	74.0
2036	19.3	21.0	37.1	19.8	66.0
2037	17.3	18.7	33.3	16.4	58.5
2038	15.4	16.5	29.7	13.3	51.5
2039	13.7	14.6	26.5	10.8	45.4
2040	12.1	12.9	23.6	8.7	39.9
2041	10.6	11.2	20.7	7.0	34.7
2042	9.3	9.8	18.2	5.5	30.0
2043	8.1	8.5	15.8	4.3	25.8
2044	7.1	7.4	13.9	3.4	22.3
2045	6.1	6.4	12.0	2.5	18.8
2046	5.4	5.6	10.5	2.1	16.4
Total	779	992	1748	2455	4011

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**APPENDIX 12A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS
SPREADSHEET MODEL**

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12A.1 USER INSTRUCTIONS

DOE performs all NIA calculations using a Microsoft Excel® spreadsheet which is available on regulations.gov, docket number EERE-2011-BT-STD-0006 at www.regulations.gov/#!docketDetail;D=EERE-2011-BT-STD-0006.

12A.2 STARTUP

The NIA spreadsheet enables the user to perform a National Impact Analysis (NIA) for the trial standard levels (TSLs) for general service fluorescent lamps (GSFL) and incandescent reflector lamps (IRL). To execute the spreadsheet, DOE assumes that the user has access to a PC with Microsoft Excel® 2007 or later installed under the Windows operating system.

12A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSIS WORKSHEETS

The NIA spreadsheets perform calculations to forecast the change in national energy use and net present value of financial impacts due to a revised energy efficiency standard. The energy use and associated costs for a given standard are determined by first calculating the shipments and then calculating the energy use and costs for all lamps shipped under that standard. The differences between the standards and base case can then be compared and the overall energy savings and net present values determined. The NIA spreadsheets consist of the following worksheets:

Introduction	Includes an introduction to the spreadsheet calculations, and information on the User Options & Summary worksheet
User Options & Summary	Includes user-selected scenarios and a summary table of the cumulative shipments, NES, and NPV under each scenario. (More information on the User Options & Summary worksheet can be found in Section 12A.4)
Charts	Includes charts of shipments, stock, NES and NPV for each standards case for the user selected scenario
Lamp Shipments & Stock-IRL	Includes historical data and the annual forecasts of shipments and stock for each standards case (IRL) for the user selected scenario
Ballast Shipments & Stock	Includes historical data and the annual forecasts of ballast shipments and stock for each standards case (GSFL) for the user selected scenario
Lamp Shipments-GSFL	Includes historical data and the annual forecasts of shipments for each standards case (GSFL) for the user selected scenario
Lamp Stock-GSFL	Includes historical data and the annual forecasts of stock for each standards case (GSFL) for the user selected scenario
Parameters and Assumptions	Includes the parameters and assumption inputs for the shipments analysis and NIA
Substitution	Includes allowed substitutions between lamp and lamp-&-ballast options (and a correction factor under said substitutions to keep light output constant)
Energy Savings	Includes the calculation of the annual energy savings for each standards case for the user selected scenario
Fuel Cost Savings	Includes the calculation of the annual fuel cost savings for each standards case for the user selected scenario
Equipment Costs	Includes the calculation of the annual equipment costs for each standards case for the user selected scenario
Net Present Value	Includes a summary of the fuel cost savings and equipment costs and the calculation

	of the annual net present values for each standards case, discounted at 3% and 7% for the user selected scenario
Fuel Prices	Includes Annual Energy Outlook (AEO) electricity price forecasts and extrapolations by sector (residential, commercial, industrial)
Site to Power Plant & Upstream	Includes annual site to power plant, and upstream conversion factors
Failure and Replacement	Includes probability distributions governing lamp and ballast failure and replacement.
Price Forecasts	Includes forecasts of lamp and ballast prices due to learning and differing assumptions about rare earth oxide prices.
Lamp Usage	Includes lamp hours of use probabilities by sector, building type and room type
LED Incursion Forecast	Includes the LED incursion forecast by sector for GSFLs and IRLs
Avg Efficacy & Wattage	Includes the shipment weighted average efficacy and wattage for lamps (IRL and GSFL) and lamp and ballast systems (GSFL only)

12A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEETS

Basic instructions for operating the NIA spreadsheets are as follows: Once the NIA spreadsheet file has been downloaded from the Internet, open the file using Excel®. If Macros have been disabled, a security warning will appear under the Ribbon. Click “Options...” to open a window titled “Security Alert-Macro”, in this window select “Enable this content” to allow Macros to run. Use Excel's® View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

Calculations are performed under a range of different sets of assumptions (scenarios), which can be selected by the user on the *User Options & Summary* worksheet. A description of the available options is given below. For each of the scenario options, the user should select one option in the associated yellow drop down menu; users must click on the yellow cell for the drop down menu to appear. Results throughout the spreadsheet will update automatically. Results are displayed for three TSLs at a time. The user can change which TSLs are visible using the TSLs to Show dropdown menu.

There are two types of scenarios that can be investigated, NIA scenarios and Shipments scenarios. NIA Scenarios do not change shipment quantities, while Shipments Scenarios change shipment quantities based on the selected options.

NIA Scenarios

Users can vary these scenarios independently of the shipments scenarios.

AEO 2013 Economic Growth Scenarios

- Reference Case
- High economic growth
- Low economic growth

Rebound Scenarios

- Reference - Assumes a 0% rebound in the commercial sector and 0% in the residential sector.
- Framework - Assumes a 1% rebound in the commercial sector and 8.5% in the residential sector
- High - Assumes a rebound rate of 15% in both sectors.

Shipment Scenarios

There are nine Alternative Scenarios users can view in the shipments scenarios listed below.

- Reference – DOE’s best-estimate scenario, Solid-state lighting (LEDs) and lighting controls grow at DOE's best-estimate rate, Rare Earth oxide (REO) prices remain at 2013 levels.
- High REO Price - REO prices remain fixed at the median price during the 2011 price spike as described in appendix 11B of this TSD
- Minimum Market Efficacy - Modeled baseline lamps for 8-foot T8 high output, T5 standard output, and T5 high output lamps are excluded from the analysis; all other variables are the same as the reference scenario.
- IRL Short Life - Baseline IRL technology remain available after standards but with shorted lifetimes, increased light output, improved efficacies, but unchanged energy consumption, all other values as in Reference.
- High Xe Price - Xenon gas prices increase by a factor of 10 and remain at that level during the analysis period.
- Fixed Controls -Lighting controls adoption remains fixed at current levels, all other values as in Reference.
- No Std-Induced PC Switching - Shipments and market shares same as the base case for all TSLs.
- No LED - LEDs do not grow into the market, all other values as in Reference.
- 9 Year Analysis - Analysis period of 2017-2025, all other values as in Reference.

APPENDIX 12B. REBOUND EFFECT

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12B.1 BACKGROUND

The U.S. Department of Energy (DOE) accounts for the direct rebound effect in its estimates of national energy savings.^a Direct rebound is the concept that an increase in the energy efficiency of equipment may indirectly induce greater usage by the end-user, thereby undercutting expected energy savings. Economic theory suggests that if efficiency improvements decrease the cost of obtaining a desired service—lighting, in this case—then demand for that service will increase, assuming demand is not saturated.

In the case of lighting, the increased usage should be normalized to floor area. Therefore, if a rebound is occurring there must be a change in lighting density (lumens per square foot). Any combination of the following potential consumer responses to increased lighting efficiency could increase lighting density and, therefore, indicate a positive rebound effect:

- an increase in the average operating hours of lamps,
- a tendency to replace less efficient lamps with more lumenous efficient lamps, and
- an increase in the number of fixtures or sockets per unit floor area (ft²).

While it is the change in service demand (lighting density in lm/ft²), concomitant with an improvement in lighting efficiency, that is the final determinant of rebound, lacking such data, rebound researchers have relied on the individual factors listed previously as proxies for lighting rebound. (See, for example, the papers by Nadel (1993)¹ and Greening et al. (2000),² which were the origin of the rebound rates proposed by DOE in the framework document for this rulemaking.) In keeping with the literature on rebound, causation is not addressed in this analysis.

Lighting rebound can be quantified by the following formula:

$$\textbf{Observed Savings} = \textbf{Expected Savings} \times (1 - rr)$$

Eq. 12B.1

Where:

Observed Savings = observed reduction in power consumption per square foot (W/ft²) during a period,

Expected Savings = expected reduction in power consumption per square foot (W/ft²), given the efficiency improvements that occurred during that period, if lighting density (lm/ft²) had remained constant, and

rr = rebound rate.

^a DOE does not include rebound effects in its NPV calculation, however, for the following reasons: The take-back in energy consumption associated with the rebound effect provides consumers with increased value (e.g., increased lighting services). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA.

Therefore, a direct rebound rate of 10 percent means that 10 percent of the energy savings expected to materialize from efficiency improvements alone would not materialize because of increased lighting density.

During the framework public meeting, the Edison Energy Institute (EEI) and the Northwest Energy Efficiency Alliance (NEEA) both commented that the rebound rates proposed by DOE for residential and commercial lighting appear too high (EEI, Public Meeting Transcript, No. 10 at p. 241; NEEA, Public Meeting Transcript, No. 10 at p. 240). In the framework document, DOE proposed an 8.5 percent rebound rate for residential lighting, based on the average of two hours-of-use studies cited by Greening et al. (2000) and a one percent rebound rate for commercial and industrial lighting, also derived from Greening *et al.* (2000).

In response to public comments, DOE conducted further research on rebound rates, starting with a review of the source materials quoted by Greening et al. (2000). The lighting rebound estimates quoted in the Greening paper were taken from Nadel (1993). Nadel, in turn, cited earlier surveys of lamp operating hours conducted by Pacific Gas & Electric Company (PG&E), Boston Edison (BE), and New England Electric System (NEES). Greening et al. used the results of quoted PG&E and BE studies only as the basis of their estimated 5 – 12 percent rebound for residential lighting. The results of the two NEES studies were not used, apparently because they had conflicting results. This may have been the genesis of the conclusion by Greening *et al.* that the data available on lighting rebound were ‘inconclusive’.^b

Given that the source data for the proposed rebound rates are now more than two decades old and were based on a single indicator of rebound (hours of use), which can be offset by other factors, DOE sought more recent evidence. Many authors have noted that appliance saturation effects can reduce rebound.^{3,4,5,6,7} Therefore, rebound rates can change significantly with time.⁴ While Greening et al. (2000), and to a lesser extent Nadel (1993), has been repeatedly cited as a source for lighting rebound rates,^{5,6,8,9} DOE found no studies that evaluated rebound rates based on more recent data. The National Energy Modeling System (NEMS) also cites Greening et al.² as the source of its rebound rates, but NEMS uses a combined average rebound rate of 15 percent for all appliances and applies that to lighting, as well as to other technologies. The NEMS assumptions for commercial rebound are described in the Energy Information Administration’s Commercial Sector Demand Module documentation for NEMS¹⁰, the rebound rate used in the residential demand module was inferred.

Lacking more recent journal publications on U.S. lighting rebound, DOE sought lighting data from which rebound rates could be estimated. DOE identified two large studies of lamp operating hours in California that are directly comparable to the original studies cited by Nadel (1993) and Greening *et al.* (2000). DOE also used lighting data from its 2001 and 2010 U.S. Lighting Market Characterization (LMC) studies, which are a better source for national rebound rates, given their scope.^{11,12} The results are described in sections 12B.2 and 12B.3.

^b See Table 3 footnote in Greening *et al.* (2000).

12B.2 OPERATING HOURS OF EFFICIENT AND STANDARD RESIDENTIAL LIGHTING IN CALIFORNIA

A 2005 study by KEMA conducted for three California utilities (PG&E, Southern California Edison Company, and San Diego Gas and Electric Company) compared hours of use of compact fluorescent lamps (CFL)¹³ to hours of use of all residential lamp types that were reported in a 1999 California Energy Commission study for the same service territory.¹⁴ These studies were based on large and more recent data sets for service areas that overlapped those reported in Nadel (1993) and Greening *et al.* and used the same metric. The sample sizes used in the two studies and the reported hours of lamp use are reported in Table 12B.2.1. The studies found no discernible difference in lamps hours of use. Given that changes in lamp operating hours are only one possible cause of rebound, and the data are only for California, DOE sought national data to check the result. These are reported in the following section.

Table 12B.2.1 Sample Disposition of Residential Lighting Studies

	KEMA 2005 ¹³	CEC 1999 ¹⁴
Residences	369	683
Fixtures	752	16,275
Lamps	1,514	26,203*
	CFLs only	All lamps
Reported Hours of Use of Lamps, Average Daily	2.3 hrs/day	2.34 hrs/day

*Total number of lamps calculated from reported average lamp per fixture values.

12B.3 NATIONAL LIGHTING DENSITY AS THE DETERMINANT OF LIGHTING REBOUND

DOE sought evidence of U.S. lighting rebound based on national lighting data reported in DOE's 2001 and 2010 U.S. LMC studies.^{11,12} As indicated in section 12B.1, by definition a positive lighting rebound occurs if there is an increase in lighting density (lm/ft^2) concomitant with an increase in lighting efficiency. A decrease in lighting density yields a negative rebound rate, indicating a greater energy savings than expected from efficiency improvements alone.

DOE used data from the two LMC reports to estimate lighting density in 2001 and 2010 using the following equation:

$$\text{Lighting Density } (\text{lm}/\text{ft}^2) = \frac{N_{\text{lamps}} * W_{\text{lamp}} * \epsilon_{\text{lamp}}}{\text{Floorspace}}$$

Eq. 12B.1

Where:

N_{lamps} = the number of lamps in the category under consideration in the United States,

W_{lamp} = the average wattage (W) of the lamp category,

ϵ_{lamp} = the average efficacy (lm/W) of the lamp category, and

Floorspace = the total floor space in the sector (ft²).

As shown in Table 12B.3.1, while reported lighting efficiency increased from 2001 to 2010, lighting density decreased, implying a negative rebound rate. The table reports the associated percentage decreases in power consumption per lumen: 5 percent in the residential sector and 21 percent in the commercial sector. In the absence of rebound, lighting power density (W/ft²) would be expected to decrease by the same amounts. Instead, it drops by considerably larger percentages: 29 and 31 percent in the residential and commercial sectors, respectively. This implies a large reduction in lighting demand: from 30 to 23 lumens per square foot in the residential sector, and from 90 to 75 lumens per square foot in the commercial sector.

Table 12B.3.1 U.S. Residential and Commercial Lighting in 2001 and 2010

	Average Efficacy ¹ E _{lamp} (lm/W)		Change in Watts per Lumen	Lamps ¹ (Millions)		Average Lamp Power ¹ (W)		Floor Space ¹ (Billion ft ²)		Average Lighting Density (lm/ft ²)		Lighting Power Density (W/ft ²)			Change in Lighting Power Density (W/ft ²)
	2001	2010		2001	2010	2001	2010	2001	2010	2001	2010	2001	2010	2010-EXP ²	
Residential	18	19	-5%	4611	5812	63	46	174	223	30	23	1.7	1.2	1.6	-29%
Commercial	55	70	-21%	1966	2069	56	42	67	81	90	75	1.6	1.1	1.3	-31%

¹ Data taken from LMC reports. All other values calculated.

² The expected power density in 2010 in the absence of rebound.

According to the LMC data, only in the residential sector are the reductions in lighting density explained (at least in part) by reductions in operating hours. As shown in Table 12B.3.2, in the residential sector lamp operating hours were estimated to have decreased by 10 percent, explaining only part of the estimated 23 percent reduction in lighting density. In the commercial sector the reported lamp operating hours increased. However, LMC 2010 indicates that the large change in estimated operating hours could be an artifact of changes in the characterization of commercial versus industrial lighting. Therefore, the results should not be considered conclusive.

Table 12B.3.2 Changes in Lamp Operating Hours Compared to Changes in Lighting Density, U.S. Residential and Commercial Sectors

Sector and Lamp Type	Average Daily Operating Hours ¹		Percent Change in Operating Hours	Average Lighting Density (lm/ft ²)		Percent Change in Average Lighting Density
	2001	2010		2001	2010	
Residential (Total)	2	1.8	-10%	30	23	-23%
Commercial (Total)	9.9	11.2	13%	90	75	-17%

¹ Data taken from LMC reports. All other values calculated.

Using the result from Table 12B.3.2, DOE estimated the rebound rates implied by the LMC data as follows:

$$rr = 1 - \frac{\text{observed power savings}}{\text{expected power savings}} \quad \text{Eq. 12B.2}$$

Where:

observed power savings = the difference between the 2001 and 2010 lighting power density, and

expected power savings = percentage change in watts per lumen multiplied by the 2001 lighting power density.

The results are reported in Table 12B.3.3.

Table 12B.3.3 Estimate rebound rates based on LMC Data

	Observed Power Savings	Expected Power Savings	Estimated Rebound Rate
Residential	0.5	0.09	-4.9 (-490%)
Commercial	0.5	0.34	-0.5 (-50%)

12B.4 CONCLUSIONS

DOE concludes that the most recent available data do not support a lighting rebound effect for either the residential or commercial sector. The data may indicate a systematic trend in residential sector rebound, moving from a modest positive rebound in the early 1990s, to zero rebound in 2005, to a very large negative rebound in 2012. An initial reduction in rebound rates from positive to zero is what is expected if demand for a service saturates. Goldstein⁴ explains that negative rebounds can occur if consumers use efficiency cost savings to invest in more energy efficiency rather than in more energy consumption. The same may be true of commercial lighting, though there are fewer data to support such a conclusion. However, given the uncertainties inherent in comparing different data sources for different times, DOE took a

conservative approach in estimating energy savings and assumed in this NOPR analysis no rebound effect for its reference scenario for both sectors. DOE also conducted a sensitivity analysis to determine the impact of the change in the assumed rebound rates compared to what had been proposed in the framework document and what has been used in NEMS. The results are described in chapter 12.

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APPENDIX 12C. FULL-FUEL-CYCLE MULTIPLIERS

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12C.1 INTRODUCTION

This appendix summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from potential standards. The FFC measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's traditional approach encompassed only site energy and the energy losses associated with generation, transmission, and distribution of electricity. Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses.¹ This appendix summarizes the methods used to incorporate the full-fuel-cycle impacts into the analysis.

This analysis uses several different terms to reference energy use. The physical sources of energy are the primary fuels such as coal, natural gas, liquid fuels, *etc.* Primary energy is equal to the heat content (Btu) of the primary fuels used to provide an end-use service. Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas and petroleum fuels are consumed at the site (for example in a furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed. For electricity, site energy is measured in kWh. In this case the primary energy is equal to the quads of primary energy required to generate and deliver the site electricity. This primary energy is calculated by multiplying the site kWh times the site-to-power-plant conversion factor, given in chapter 12. For the FFC analysis, the upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in fuel cycle analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable fluxes (wind, solar and hydro). For the former, the upstream fuel cycle impacts are derived from the amount of fuel consumed at the power plant. For the latter, no fuel *per se* is used, so there is no upstream component.

12C.2 METHODOLOGY

The mathematical approach is discussed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use*,² and details on the fuel production chain analysis are presented in the paper *Projections of Full Fuel Cycle Energy and Emissions Metrics*³ The text below provides a brief summary of the methods used to calculate FFC energy.

When all energy quantities are normalized to the same units, the FFC energy use can be represented as the product of the primary energy use and an *FFC multiplier*. The FFC multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, so the calculations do not require any assumptions about prices or other economic data. While in general these parameter values may vary by geographic region, for this analysis national averages are used.

In the notation below, the indices x and y are used to indicate fuel type, with $x=c$ for coal, $x=g$ for natural gas, $x=p$ for petroleum fuels, $x=u$ for uranium and $x=r$ for renewable fluxes. The fuel cycle parameters are:

- a_x is the quantity of fuel x burned per unit of electricity output, on average, for grid electricity. The calculation of a_x includes a factor to account for transmission and distribution system losses.
- b_y is the amount of grid electricity used in production of fuel y , in MWh per physical unit of fuel y .
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y .
- q_x is the heat content of fuel x (MBtu/physical unit)^a
- $z_x(s)$ is the emissions intensity for fuel x (mass of pollutant s per physical unit of x)

The parameters are calculated as a function of time with an annual time step; hence, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period. Fossil fuel quantities are converted to energy units using the heat content factors q_x . To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-power-plant conversion factor indicated in chapter 12. The site-to-power-plant conversion factor is defined as the ratio of the total primary energy consumption by the electric power sector (in quadrillion Btu) divided by the total electricity generation in each year.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. A multiplier is also calculated for electricity reflecting the fuel mix used in its generation. The multipliers are dimensionless numbers that are applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to $(\mu-1)$. The fuel type is denoted by a subscript on the multiplier μ .

For DOE's appliance standards energy savings estimates, the fuel cycle analysis methodology is designed to make use of data and projections published in the *Annual Energy Outlook (AEO)*. Table 12C.2.1 provides a summary of the *AEO* data used as inputs to the different parameter calculations. The *AEO* does not provide all the information needed to estimate total energy use in the fuel production chain. Reference 3 describes the additional data sources used to complete the analysis. However, the time dependence in the FFC multipliers arises exclusively from variables taken from the *AEO*. The FFC analysis for this preliminary analysis used data from *AEO 2012*.⁴

^a Where MBtu = 1000 Btu.

Table 12C.2.1 Dependence of FFC Parameters on AEO Inputs

Parameter	Fuel	AEO Table	Variables
q_x	all	Conversion Factors	MBtu per physical unit
a_x	all	Electricity Supply, Disposition, Prices, and Emissions	Generation by fuel type
		Energy Consumption by Sector and Source	Electric power sector energy consumption
b_c, c_{nc}, c_{pc}	coal	Coal Production by Region and Type	Production by coal type and sulfur content
b_p, c_{np}, c_{pp}	petroleum	Refining Industry Energy Consumption	Refining only energy use
		Liquid Fuels Supply and Disposition	Crude supply by source
		International Liquids Supply and Disposition	Crude oil imports
		Oil and Gas Supply	Crude oil domestic production
c_{nn}	natural gas	Oil and Gas Supply	US dry gas production
		Natural Gas Supply, Disposition and Prices	Pipeline, lease and plant fuel
z_x	all	Electricity Supply, Disposition, Prices and Emissions	Power sector emissions

12C.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

FFC energy multipliers are presented in Table 12C.3.1 for selected years. To extend the analysis period beyond 2035, the last year in the *AEO 2012* projection, the years 2020 to 2035 are used to define a linear trend to 2040, which is then extrapolated to the final year of the analysis period. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation over the forecast period.

Table 12C.3.1 Full Fuel Cycle Energy Multipliers (Based on AEO 2012)

	2015	2020	2025	2030	2035	2040
Electricity (power plant primary energy use)	1.042	1.041	1.040	1.040	1.041	1.041
Natural Gas (site)	1.102	1.103	1.100	1.099	1.098	1.097
Petroleum Fuels (site)	1.142	1.146	1.153	1.163	1.172	1.181

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APPENDIX 13A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

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APPENDIX 13A. MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

13A.1 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR GENERAL SERVICE FLUORESCENT LAMPS

Summer 2013

The US Department of Energy (DOE) is conducting a manufacturer impact analysis (MIA) as part of the rulemaking process to amend energy conservation standards for general service fluorescent lamps (GSFLs). In this analysis, DOE uses publicly available information and information provided during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

1 PRELIMINARY ANALYSIS FOLLOW-UP

On February 28, 2013 DOE published a *Federal Register* notice announcing the availability of the preliminary technical support document.¹ The following questions expand upon topics discussed in that document and at the April 9, 2013 public meeting.

Scope

- 1.1 What is the most popular lamp length among the less than 4-foot linear fluorescent lamps?
- 1.2 DOE received comments that the scope of coverage should be expanded to include 2-foot linear lamps based on market share. What percentage of fluorescent lamp shipments do 2-foot medium bipin (MBP) linear lamps comprise? What percentage of fluorescent lamp shipments do 2-foot miniature bipin (MiniBP) linear lamps comprise? By how much do you think these percentages will increase/decrease in the future?
- 1.3 Why do consumers choose 2-foot linear lamps over other lamp lengths/shapes? For what applications are 2-foot linear lamps generally used?
- 1.4 A 2013 study on the state of Vermont conducted by the Northeast Energy Efficiency Partnerships, showed that of over 136,000 lamps surveyed, 2-foot linear lamps represented 6.3% of installed fluorescent lamps including 3.6% of high performance T8s, 9.3% of standard efficiency T8s, 3.9% of T12s, and 5.2% of T5s. Do you think these numbers are representative of the nation or a potential national trend?

Technology Options

- 1.5 A patent for multimodal rare earth phosphors (phosphor activated by at least one rare earth element which comprises particles having a multimodal particle size distribution) was published recently.² Is this higher efficiency phosphor practicable to manufacture? Have multimodal phosphors reached commercialization? What are the expected gains in efficacy from using multimodal rare earth phosphors?

¹ For more details about the analysis that has been done to date, please visit DOE's website at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24

² www.google.com/patents/US20120286645

- 1.6 DOE received comments that krypton-filled lamps are not able to dim reliably in many applications. How does industry define a “dimmable” lamp? Please specify any relevant performance requirements.
- 1.7 Please describe the problems encountered when dimming krypton-filled lamps (e.g., cannot dim to certain level, maintaining dimming, etc.). Are issues with dimming exclusively caused by the use of krypton? Do lamps that utilize rare gases other than krypton experience the same issues?
- 1.8 What amount of krypton in a lamp begins to impact dimmability? Do issues with dimming get worse as more krypton is used?
- 1.9 What types of lamps contain krypton? Do full wattage lamps contain krypton? Do all versions of reduced wattage lamps within a product class experience problems dimming (e.g., both the 28 W and 25 W lamp in the 4-foot MBP product class)?
- 1.10 For GSFLs, why is krypton used to increase lamp efficacy? Why is krypton preferred to other fill gases? Is it possible to achieve higher efficacy levels by minimizing krypton or using other fill gases?
- 1.11 Does your company manufacture any reduced wattage lamps that contain an alternative gas in place of or in addition to krypton such as argon, xenon, or neon?
- 1.12 What is the current status of efforts to improve the dimmability of lamps that utilize krypton?

Engineering Analysis

- 1.13 In Table 13A.1-1 through Table 13A.1-5, please review the information on efficacy and typical characteristics of the representative lamp units and provide further information on design pathways for achieving higher efficacies. DOE used lamp catalogs to identify representative lamp units and determine efficacy levels. These levels were then adjusted if compliance efficacies for representative lamp units were lower than their catalog values. The resulting proposed levels are shown in the far right column in the table below. Please indicate which of your product lines would be at each baseline level and efficacy level (EL).

Table 13A.1-1 4-foot MBP (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lumens/watt [lm/W])	Key Design/Technology Characteristics*	Product Line	Medium End-User Price (2011\$)	Proposed Efficacy Level (lm/W)
Baseline	32 W T8	89.2	Full wattage 800 series; initial lumens 2,900; 24,000 lifetime		5.36	No proposed level
EL 1	32 W T8	90.0	Full wattage improved 800 series; initial lumens 2,925; 21,000 hour lifetime		5.65	90.0
EL 2	25 W T8	93.0	Reduced wattage 800 series; initial lumens 2,475; 24,000 hour lifetime		8.68	93.0
	32 W T8	95.4	Full wattage high lumen 800 series; initial lumens 3,100; 24,000 hour lifetime		7.42	
	28 W T8	96.0	Reduced wattage 800 series; initial lumens 2,725; 24,000 hour lifetime		6.49	
EL 3 Maximum Technologically Feasible	32 W T8	101.5	Full wattage high lumen improved 800 series; initial lumens 3,300; 24,000 hour lifetime		9.39	101.5

* Average rated lifetime based on 3 hour instant starts

Table 13A.1-2 8-foot Single Pin (SP) Slimline (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W)	Key Design/Technology Characteristics*	Product Line	Medium End-User Price (2011\$)	Proposed Efficacy Level (lm/w)
Baseline	59 W T8	96.5	Full wattage 800 series; 5,800 initial lumens; 24,000 hour lifetime		8.41	No proposed level
EL 1	59 W T8	98.2	Full wattage improved 800 series; 5,900 initial lumens; 24,000 hour lifetime		9.82	98.2
EL 2 Maximum Technologically Feasible	59 W T8	99.0	Full wattage further improved 800 series; 5,950 initial lumens; 24,000 hour lifetime		13.38	99.0
	54 W T8	105.6	Reduced wattage 800 series; 5,700 initial lumens; 24,000 hour lifetime		15.67	
	50 W T8	108.0	Reduced wattage 800 series; 5,400 initial lumens; 24,000 hour lifetime		19.20	

* Average rated lifetime based on 3 hour instant starts

Table 13A.1-3 8-foot Recessed Double Contact (RDC) HO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W)	Key Design/Technology Characteristics*	Product Line	Medium End-User Price (2011\$)	Proposed Efficacy Level (lm/w)
Baseline	86 W T8	92	Modeled baseline; full wattage less efficient 700 series; 7,728 initial lumens; 18,000 hour lifetime		8.53	No proposed level
EL 1	86 W T8	95.2	Full wattage 700 series; 8,000 initial lumens; 18,000 hour lifetime		11.75	94.0
EL 2 Maximum Technologically Feasible	86 W T8	97.6	Full wattage 800 series; 8,200 initial lumens; 18,000 hour lifetime		14.15	97.6

* Average rated lifetime based on 3 hour instant starts

Table 13A.1-4 4-foot T5 MiniBP SO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W) at 35 °C	Efficacy (lm/W) at 25 °C	Key Design/Technology Characteristics*, **	Product Line	Medium End-User Price (2011\$)	Proposed Efficacy Level (lm/w) at 25 °C
Baseline	28 W T5	94.6	86	Modeled baseline; full wattage less efficient 800 series; 2,630 initial lumens (2,391 at 25 °C); 30,000 hour lifetime		3.99	No proposed level
EL 1	28 W T5	104.3	93.5	Full wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 30,000 hour lifetime		5.51	93.5
EL 2	28 W T5	109.7	98.2	Full wattage improved 800 series; 3,050 initial lumens (2,730 at 25 °C); 30,000 hour lifetime		6.44	98.2
EL 3 Maximum Technologically Feasible	26 W T5	115.0	100.0	Reduced wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 30,000 hour lifetime		8.17	100.0
	28 W T5	110.8	100.7	Full wattage further improved 800 series; 3,080 initial lumens (2,800 at 25 °C); 30,000 hour lifetime		6.87	
	25 W T5	116.0	104.0	Reduced wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 35,000 hour lifetime		9.51	

* Where lumen output at 25 °C is not provided in catalogs, lumen output is estimated as 10% lower than lumen output at 35 °C.

** Average rated lifetime based on 3 hour programmed starts

Table 13A.1-5 4-foot T5 MiniBP HO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W) at 35 °C	Efficacy (lm/W) at 25 °C	Key Design/Technology Characteristics*, **	Product Line	Medium End-User Price (2011\$)	Proposed Efficacy Level (lm/w) at 25 °C
Baseline	54 W T5	83.6	76	Modeled baseline; less efficient 800 series; 4,498 initial lumens (4,089 at 25 °C); 24,000 hour lifetime		6.40	No proposed level
EL 1	54 W T5	92.9	82.7	Full wattage 800 series; 5,000 initial lumens (4,450 at 25 °C); 25,000 hour lifetime		6.91	82.7
EL 2 Maximum Technologically Feasible	54 W T5	97.2	88.4***	Full wattage improved 800 series; 5,173 initial lumens (4,703 at 25 °C); 45,000 hour lifetime		13.36	88.4
	49 W T5	102.0	90.8	Reduced wattage 800 series; 5,000 initial lumens (4,450 at 25 °C); 35,000 hour lifetime		11.29	
	47 W T5	102.1	91.9	Reduced wattage 800 series; 4,800 initial lumens (4,319 at 25 °C); 30,000 hour lifetime		12.61	

* Where lumen output at 25 °C is not provided in catalogs, lumen output is estimated as 10% lower than lumen output at 35 °C,

** Average rated lifetime based on 3 hour programmed starts

***The efficacy and initial lumens for this lamps are based on compliance values.

1.14 Do you use proprietary technology in any of your GSFL products? If so, please explain. Is proprietary technology necessary to achieve the efficacy levels being considered?

1.14 DOE selects baseline models within a representative product class. The baseline model typically represents the most common, least efficacious lamp available. Do you agree with the baseline models selected in the tables above?

1.15 Do you anticipate offering commercially available products that just meet the current standard level for the 8-foot HO, T5 SO, and T5 HO product classes? If so, please indicate for which product class, the targeted release date, and any estimated lamp performance characteristics such as wattage, lumens, lifetime, etc.

1.16 Where the compliance values for representative lamp units are higher than the catalog values DOE is considering setting the efficacy level at the higher compliance values. Do you agree with this approach?

- 1.17 Are the medium end-user prices developed in the engineering analysis and displayed in the tables above representative of your company's products? If not, please provide a quantitative indication of the differences.
- 1.18 In the NOPR, DOE will calculate manufacturer selling prices (MSPs). See section 13A.14 for a description of MSP. DOE is considering using a markdown of 1.53 to go from the medium end-user prices to the MSP. Do you agree with this approach?
- 1.19 DOE received comments that ANSI has drafted new standards for fluorescent lamps based on high frequency operation. Have these new standards been finalized? If not, when do you anticipate it will be? How long will it take for catalogs to reflect this change?
- 1.20 What do the values of initial efficacy in catalogs represent? Do they represent long-term average data?

T5 HO Lamp

- 1.21 Table 13A.1-5 lists higher efficacy full wattage T5 HO lamps based on compliance data. Do the listed efficacies for these 54 W lamps reflect the achievable efficacy for this lamp type? If you are not already offering higher efficacy full wattage T5 HO lamps, do you plan to in the future? If so, please provide estimated performance characteristics for these lamps.

Max Tech

- 1.22 Table 13A.1-6 lists the most efficient level in each representative product class. Please provide any efficacy improvements that may be possible as well as the associated cost increase expected.

Table 13A.1-6 GSFL Max Tech Levels for Representative Product Classes

Product Class	Highest Efficacy Commercially Available Product Analyzed	Potential Efficacy Improvement	Design Pathway	Associated Cost Increase
4-foot MBP	101.5 lm/w			
8-foot SP slimline	99.0 lm/w			
8-foot RDC HO	97.6 lm/w			
4-foot T5 MiniBP SO	100.0 lm/w*			
4-foot T5 MiniBP HO	88.4*			

* Efficacy at 25 °C

Scaling

- 1.23 In the preliminary analysis DOE identified one scaling factor for all products with a CCT greater than 4,500 K. However, based on an assessment of catalog and compliance data, DOE is considering establishing individual scaling factors for each product class with a CCT greater than 4,500K as follows: 2% for the 4-foot MBP, 4% for 2-foot U-shaped, 5% for 8-foot slimline, 2% for 8-foot RDC HO, 6% for T5 MiniBP SO, and 5% for T5 MiniBP HO. Do you agree with this assessment?

Lamp System Replacements

- 1.24 In replacements of lamps and/or lamp-and-ballast systems, what occurs more often in practice: maintenance of less than 10 percent of the mean lumen output of the replaced system or maintenance of more than 10 percent of the mean lumen output of the replaced system? What is the percentage change in light output (decrease and increase) that is noticed by consumers after a retrofit? Are there industry recommendations, such as from the Illuminating Engineering Society (IES), that specify lumen maintenance in retrofit scenarios?
- 1.25 Is reducing energy consumption typically favored over increasing or maintaining light output in retrofits?
- 1.26 Given that the mean lumen output of the 25 W 4-foot MBP lamp is about 14% percent lower than the lumen output of the baseline 32 W lamp, in what applications are 25 W lamps typically used? If not used in new construction, what systems do 25 W lamp-and-ballast systems typically replace? Is the 25 W lamp a popular product?
- 1.27 DOE received feedback that delamping should be considered as a replacement scenario. How common is delamping when conducting retrofits of existing lighting systems? Does this occur when replacing T8 systems?

Product Price Determination

- 1.28 In the preliminary analysis, DOE developed end-user prices by determining discounts based on the product's distribution channel. DOE identified three main distribution channels and associated end-user prices for GSFLs: state procurement channel used to develop the low end-user price; large distributors including do-it-yourself stores to develop medium end-user prices; and internet retailers to develop high end-user prices.

DOE is considering weighting end-user prices by percentage of shipments for each distribution channel (i.e., low, high, and medium). Please provide the percentage of shipments for each distribution channel for GSFLs.

2 KEY ISSUES

- 2.1 In general, what are the key issues for your company regarding amended energy conservation standards and this rulemaking?
- 2.2 For the issues identified, how significant are they for each efficacy level? See Table 13A.1-1 through Table 13A.1-5 of the interview guide for a description of efficacy levels.
- 2.3 Are any of the issues more or less significant for different product classes or GSFL types?

Please refer to Table 13A.1-7 for a list of product classes.

Table 13A.1-7 Product Classes Under Consideration

Lamp Type	CCT Division
4-foot medium bipin	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$
2-foot U-shaped	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$
8-foot single pin slimline	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$
8-foot recessed double contact high output	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$
4-foot miniature bipin standard output	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$
4-foot miniature bipin high output	$CCT \leq 4500K$
	$CCT >4500K \text{ and } \leq 7000K$

3 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to GSFL production. However, the context surrounding plant operation and details of plant production and costs are not always readily available from public sources. DOE is interested in gaining a more nuanced understanding of these issues and invites you to provide these details confidentially. Understanding the organizational setting around the GSFL industry profit center will help DOE assess the probable future of GSFL manufacturing activity with and without amended energy conservation standards.

- 3.1 Do you have a parent company, and/or any subsidiaries relevant to the GSFL industry?
- 3.2 What is your company's approximate market share of the GSFL market? Does this vary significantly for any particular product class that you manufacture?
- 3.3 Do you manufacture any products other than GSFLs? If so, what other products do you

manufacture? What percentage of your total manufacturing revenue corresponds to GSFLs?

Please complete Table 13A.1-8 to the best of your ability. If possible, please express revenue in both dollar amount and in percentage of total GSFL sales. Additionally, please express shipments in both volume and percentage of all GSFL shipments. Please indicate if you do not manufacture products in any given product class.

Table 13A.1-8 GSFL Percent Revenue and Shipment Volumes by Product Class

GSFL Product Class	2012 Revenue		2012 Shipments	
	\$	% of Total GSFL Sales	Units	% of Total GSFL Sales
4-foot MBP $\leq$ 4,500 K				
4-foot MBP $>$ 4,500 K				
2-foot U-Shaped $\leq$ 4,500 K				
2-foot U-Shaped $>$ 4,500 K				
8-foot SP slimline $\leq$ 4,500 K				
8-foot SP slimline $>$ 4,500 K				
8-foot RDC HO $\leq$ 4,500 K				
8-foot RDC HO $>$ 4,500 K				
4-foot T5 MiniBP SO $\leq$ 4,500 K				
4-foot T5 MiniBP SO $>$ 4,500 K				
4-foot T5 MiniBP HO $\leq$ 4,500 K				
4-foot T5 MiniBP HO $>$ 4,500 K				

4 MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how amended energy conservation standards would impact your company's markup structure and profitability.

DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. These include direct labor, direct materials, and overhead (which includes depreciation). The manufacturer markup is a multiplier applied to manufacturer production cost to cover non-production costs, such as selling, general, and administrative (SG&A) expenses and research and development (R&D) expenditures, as well as profit. *It does not reflect a "profit margin."* This is also sometimes referred to as "gross margin."

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

DOE estimated a markup of 1.58 for all general service fluorescent lamps.

- 4.1 Is the 1.58 markup representative of an average industry markup?
- 4.2 Please comment on the markup DOE calculated compared to your company's markup for GSFLs.
- 4.3 Do profit levels vary by product class or product line? If yes, please indicate why.
- 4.4 Because the market disruption caused by efficiency standards can alter the pricing of premium products, DOE is interested in understanding how margins currently change with efficiency. Within each product class, do markups vary by efficiency level? If yes, please provide information about the markups at higher efficiencies.
- 4.5 What factors besides efficiency affect the profitability of GSFLs within a product class?
- 4.6 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 SHIPMENT PROJECTIONS

- 5.1 How common is it for 4-foot T5 MiniBP SO lamp-and-ballast systems to serve as replacements for 4-foot T8 MBP lamp-and-ballast systems? Assuming comparable lumen output, is there a difference in the average cost of fixtures for 4-foot T8 MBP and 4-foot T5 MiniBP SO systems? If so, please provide an estimate of the cost difference or data thereon.
- 5.2 Please provide an estimate of shipments of high CRI (≥ 87) fluorescent lamps. Are these products popular? In what applications are these products used? Please describe expected future shipments of high CRI fluorescent lamps.
- 5.3 How do shipments of T12 lamps compare with T8 and T5 lamps? Are standards-compliant T12 lamps popular? Please describe expected future shipments of T12 products.
- 5.4 Please provide the percentage breakdown of shipments by low, normal, and high ballast factor for the following lamp types: 4-foot MBP, 8-foot SP slimline, 8-foot RDC HO, 4-foot T5 MiniBP SO, and 4-ft T5 MiniBP HO.

- 5.5 Can you please provide an estimate of the (shipment-weighted) average number of lamps installed per ballast in recent years, for each of the lamp types considered in this rulemaking?
- 5.6 Do you expect characteristics of GSFLs to change in response to amended standards? If so, please describe the potential changes to GSFL characteristics.
- 5.7 Do you expect your market share to change when amended energy conservation standards require compliance? If so, please describe the potential changes in market shares.

6 FINANCIAL PARAMETERS

- 6.1 In order to accurately collect information about GSFL manufacturing, please compare your financial parameters to the GRIM parameters tabulated below.

Table 13A.1-9 Financial Parameters for GSFL Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	31.2%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.2%	
Working Capital	Current assets less current liabilities (percentage of revenues)	4.9%	
Net PPE	Net plant property and equipment (percentage of revenues)	18.2%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	17.9%	
R&D	Research and development expenses (percentage of revenues)	4.5%	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.5%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.4%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	63.4%	

- 6.2 Do any of the financial parameters in
- 6.3 Table 13A.1-9 change significantly based on product class (see Table 13A.1-7 for a list of product classes)? Please describe any differences.
- 6.4 Do any of the financial parameters in

- 6.5 Table 13A.1-9 change for a particular subgroup of manufacturers? Please describe any differences.
- 6.6 How would you expect amended energy conservation standards to impact any of the financial parameters for the industry?
- 6.7 Can you please provide the breakdown in the total production costs for GSFLs by the percentage for labor, materials, overhead, and depreciation by filling in Table 13A.1-10 below?

Table 13A.1-10 Breakdown of Total Production Costs for GSFLs

Labor % of full production costs	Materials % of full production costs	Overhead % of full production costs	Depreciation % of full production costs

7 CONVERSION COSTS

DOE understands that amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing production lines. Understanding the nature and magnitude of the conversion costs is a critical part of the MIA. Depending on their magnitude, the conversion costs can have a substantial effect on the outputs used by DOE to evaluate the impact of amended energy conservation standards on the GSFL industry. The MIA considers two types of conversion costs:

- *Capital conversion costs* are one-time investments in plant, property, and equipment (PPE) necessitated by amended energy conservation standards. These may be incremental additions to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- *Product conversion costs* are costs related to research, product development, testing, marketing and other costs for redesigning products necessitated by amended energy conservation standards.

Table 13A.1-1 through Table 13A.1-5 show efficacy and typical characteristics of the representative lamp units. DOE asks a number of questions to understand the nature and magnitude of your expected capital and product conversion costs. Please refer to these tables when considering your response to the following questions.

At your manufacturing facilities, would the design options you would choose to meet these ELs be difficult to implement? If so, would your company modify the existing facility or develop a new facility?

- 7.1 Are there certain design options that would require relatively minor changes to existing

products?

- 7.2 Are there certain efficacy levels where the capital or product conversion costs significantly increase over the previous efficacy levels? Would your answer change for different product classes? Please describe these changes qualitatively.
- 7.3 For each of the product classes shown in Table 13A.1-7, which ELs could be achieved within existing platform designs and which would result in major product redesigns?

Please provide estimates for your capital conversion costs by product class in

- 7.4 Table 13A.1-11 below. In the description column, DOE is interested in understanding the kinds of changes that would need to be implemented to production lines and production facilities at each efficacy level. Where applicable, please quantify the number and cost of new production equipment, molds, etc., that would be required to implement the specified design changes.

What product conversion costs would you expect to incur to achieve each of these efficacy levels for each product class? Please provide your estimates in

- 7.5 Table 13A.1-11 below considering, such expenses as product development, prototyping, testing, certification, and marketing. In the description column, please describe the assumptions behind the estimates provided.

Table 13A.1-11 Expected Product and Capital Conversion Costs for GSFLs

Product Class	EL	Total Product Conversion Costs (\$)	Total Capital Conversion Costs (\$)	Description
4-Foot Medium Bipin CCT ≤ 4500K	Baseline			
	1			
	2			
	3			
8-Foot Single Pin Slimline CCT ≤ 4500K	Baseline			
	1			
	2			
8-Foot Recessed Double Contact High Output CCT ≤ 4500K	Baseline			
	1			
	2			
4-Foot Miniature Bipin Standard Output CCT ≤ 4500K	Baseline			
	1			
	2			
	3			
4-Foot Miniature Bipin High Output CCT ≤ 4500K	Baseline			
	1			
	2			

8 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards and/or other regulatory actions affecting the same product or industry.

- 8.1 Below is a list of regulations that could affect manufacturers of GSFLs. Please provide any comments on the listed regulations and provide an estimate for your expected compliance cost.

Table 13A.1-12 Other Regulations Identified by DOE

Regulation	Estimated or Actual Effective Date(s)	Expected Expense for Compliance	Comments
DOE's Energy Conservation Standards for Other Products and Equipment			
International Energy Efficiency Standards			
Restriction of Hazardous Substances (RoHS)			
Others			

8.2 Are there any other recent or impending regulations that GSFL manufacturers face (from DOE or otherwise)? If so, please identify the regulation, the corresponding effective dates, and your expected compliance cost.

8.3 Under what circumstances would you be able to coordinate any expenditure related to these other regulations with amended energy conservation standards?

9 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in GSFL employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

9.1 Where are your GSFL facilities that produce products for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's GSFL manufacturing at each location by product class. Please also provide employment levels at each of these facilities.

Table 13A.1-13 GSFL Manufacturing Facilities

Facility	Location	Product Types Manufactured	Employees	Annual Shipments
<i>Example</i>	<i>Jackson, TN</i>	<i>4-foot MBP, T5 SO</i>	<i>650</i>	<i>300,000 for 4-foot MBP, 200,000 for T5 SO</i>
1				
2				
3				
4				
5				

9.2 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how and why they would change if higher efficacy levels were required.

9.3 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?

9.4 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

10 MANUFACTURING CAPACITY AND NON-US SALES

10.1 How would amended energy conservation standards impact your company's manufacturing capacity?

10.2 For any design changes that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your business? Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

10.3 What percentage of your company's GSFLs sold within the United States is manufactured domestically?

10.4 What percentage of your US production of GSFLs is exported?

10.5 Are there any foreign companies with North American production facilities?

10.6 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficacy level that would cause you to move existing domestic production facilities outside the U.S.?

11 IMPACT ON COMPETITION

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

- 11.1 How would industry competition change as a result of amended energy conservation standards? How would amended energy conservation standards affect *your* ability to compete in the marketplace? Would the effects on your company be different than others in the industry?
- 11.2 Do you or any other firms hold intellectual property that gives them a competitive advantage following amended energy conservation standards?

12 IMPACTS ON SMALL BUSINESSES

- 12.1 The Small Business Administration (SBA) denotes a small business in the GSFL manufacturing industry as having less than 1,000 total employees, including the parent company and all subsidiaries.³ By this definition, is your company considered a small business?
- 12.2 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.
- 12.3 To your knowledge, are there any small businesses for which the adoption of amended energy conservation standards would have a particularly severe impact? If so, why?
- 12.4 To your knowledge, are there any niche manufacturers or component manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact? If so, why?

³ DOE uses the small business size standards published on January 7, 2013, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, an electric lamp manufacturer and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

**13A.2 MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR
INCANDESCENT REFLECTOR LAMPS**

Summer 2013

The U.S. Department of Energy (DOE) is conducting a manufacturer impact analysis (MIA) as part of the rulemaking process to amend energy conservation standards for incandescent reflector lamps (IRLs). In this analysis, DOE uses publicly available information and information provided during interviews to assess possible impacts on manufacturers due to amended energy conservation standards.

1 PRELIMINARY ANALYSIS FOLLOW-UP

On February 28, 2013 DOE published a *Federal Register* notice announcing the availability of the preliminary technical support document.⁴ The following questions expand upon topics discussed in that document and at the April 9, 2013 public meeting.

Technology Options

- 1.1 One technology option under consideration for improving the efficacy of IRLs is an integral ballast that allows the lamp to operate at low voltage instead of line voltage. DOE received comments that this technology option cannot be used for high wattage products.
- 1.2 What are the specific reasons that an integrally ballasted low voltage technology cannot be used at higher wattages? What is the wattage threshold above which this technology will not work? Do any of your IRL product lines use integrally ballasted low voltage technology? For which products would you consider using this technology option in the future?
- 1.3 Do you use a fill gas other than xenon in your products? If so, please provide the alternative gas used and which product lines use it. How does the use of an alternative gas impact lamp efficacy? Are there any plans to change the type of fill gas used in any of your product lines?
- 1.4 What is the typical amount of xenon used in your lamps? Does this vary with your product lines?
- 1.5 Do you utilize both single-ended and double-ended burners in your lamps? Are single-ended burners used in large diameter lamps?
- 1.6 Please specify the typical burner length for single-ended and double-ended burners used in your lamps. If burner length varies, please specify the range.
- 1.7 DOE received comments that efficient filament placement should not be a technology option because filaments are already placed in the optimal position to achieve the highest

⁴ For more details about the analysis that has been done to date, please visit DOE's website at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24.

efficacy in all lamps. Do you think improved filament placement is a viable option for increasing the efficacy of your commercially available lamps?

Engineering Analysis

- 1.8 Table 13A.2-1 presents the baseline and efficacy levels (ELs) under consideration. Please review the information on efficacy and typical characteristics of the representative lamp units and provide further information on key design/technology characteristics for achieving higher efficacies, and which of your product lines have the characteristics of each level.

Table 13A.2-1 IRL Engineering Analysis

Level*	Lamp Type	Certification Values*			Lifetime (hrs)	Efficacy Level Equation (lm/w)	Key Design/Technology Characteristics	Medium End-User Price (2011\$)
		Watt	Lumens	Efficacy (lm/w)				
Baseline	60W PAR38	60W	1,070	17.8	1,500	$5.9P^{0.27}$	Halogen technology using higher efficiency reflector coating	8.91
EL 1	55W PAR38	56W	1,036	18.5	2,500	$6.2P^{0.27}$	Halogen infrared (HIR) technology	11.40
	55W PAR38	55W	1,018	18.5	4,200	$6.2P^{0.27}$	HIR technology using higher efficiency reflector coating	13.76
EL2	50W PAR38	53W	1,044	19.7	3,000	$6.7P^{0.27}$	HIR technology using higher efficiency reflector coating	15.41
EL 3**	45W PAR30	45W	981	21.8	3,000	$7.8P^{0.27}$	Advanced HIR technology using more advanced efficiency reflector coating	16.34

P = rated wattage

*All wattages and lumens are based on certification data except for the baseline level which are catalog values and reflect the existing standard.

**Level based on the highest certification efficacy submitted for DOE compliance.

- 1.9 What do the values of initial efficacy in catalogs represent? Do they represent long-term average data?
- 1.10 Are the medium end-user prices developed in the engineering analysis and displayed in the tables above representative of your company's products? If not, please provide a quantitative indication of the differences.
- 1.11 In the NOPR, DOE will calculate manufacturer selling prices (MSPs). See section 4 for a description of MSP. DOE is considering using a markdown of 1.53 to go from the

medium end-user prices to the MSP. Do you agree with this approach?

- 1.12 DOE would like to further explore the relationship between lifetime and efficacy in IRLs. Please fill out the following table using your product lines and assuming each product line has a lifetime of 1,500 hours. Additional rows may be added if necessary.

Table 13A.2-2 IRL Shortened Lifetime Levels

Level	Lamp Type	Lumens	Efficacy (lm/W)	Efficacy Level Equation (lm/w)	Lifetime (hours)	Key Design/Technology Characteristics	Medium End-User Price (2011\$)
Baseline				$5.9P^{0.27}$	1,500		
EL 1					1,500		
EL 2					1,500		
EL 3					1,500		

- 1.13 Completion of the table above assumes that certain relationships exist between lifetime, lumens, and watts. Please provide any equations used to complete the table.
- 1.14 Why do end-users purchase products with different lifetimes? Who most commonly purchases a 1,500 hour product? A 3,000 hour product? A 4,200 hour product?
- 1.15 What is the minimum acceptable lifetime for end-users of these lamps? Please explain.
- 1.16 Do you plan to introduce new IRL products? If so, please describe them and provide initial performance characteristics such as wattage, lumens, and lifetime. When do you expect them to be available?
- 1.17 Do you use proprietary technology in any of your IRL products? If so, please describe the proprietary technology and how it is used in your products. Is this proprietary technology necessary to achieve the efficacy levels being considered?
- 1.18 Do any other firms hold intellectual property that gives them a competitive advantage?
- 1.19 Max Tech: DOE is required to consider the maximum technologically feasible energy conservation standard. Table 13A.2-3 lists the most efficient level in the representative product class. Please provide any efficiency improvements that may be possible beyond this level as well as the associated cost increase expected.

Table 13A.2-3 IRL Max Tech Level for Representative Product Class

Max Tech Level	Potential Efficiency Improvement	Design Pathway	Associated Cost Increase
7.8P ^{0.27} (21.8 lm/w at 45 W)			

- 1.20 In the Preliminary Analysis, DOE modeled lamps with single-ended burners by using a reduction of 3.5 percent in efficacy going from a double-ended to single-ended burner. Is this reduction appropriate? If not, please explain.

Product Price Determination

- 1.21 In the preliminary analysis, DOE developed end-user prices by determining discounts based on the product's distribution channel. DOE identified three main distribution channels and associated end-user prices for IRLs: state procurement channel used to develop the low end-user price; large distributors including do-it-yourself stores to develop medium end-user prices; and internet retailers to develop high end-user prices.

DOE is considering weighting end-user prices by percentage of shipments for each distribution channel (i.e., low, high, and medium). Please provide the percentage of shipments for each distribution channel for IRLs.

2 KEY ISSUES

- 2.1 In general, what are the key issues for your company regarding amended energy conservation standards and this rulemaking?
- 2.2 For the issues identified, how significant are they for each efficacy level? See Table 13A.2-1 of the interview guide for a description of efficacy levels.
- 2.3 Are any of the issues more or less significant for different product classes or IRL types? Please refer to **Error! Reference source not found.** for a list of product classes.

Table 13A.2-4 IRL Product Classes Under Consideration

Lamp Type	Diameter	Voltage
Standard Spectrum	> 2.5 inches	≥ 125 V
		< 125 V
	≤ 2.5 inches	≥ 125 V
		< 125 V
Modified Spectrum	> 2.5 inches	≥ 125 V
		< 125 V
	≤ 2.5 inches	≥ 125 V
		< 125 V

**Gray shading indicates a representative product class*

3 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to IRL production. However, the context surrounding plant operation and details of plant production and costs are not always readily available from public sources. DOE is interested in gaining a more nuanced understanding of these issues and invites you to provide these details confidentially. Understanding the organizational setting around the IRL industry profit center will help DOE assess the probable future of IRL manufacturing activity with and without amended energy conservation standards.

- 3.1 Do you have a parent company, and/or any subsidiaries relevant to the IRL industry?
- 3.2 What is your company's approximate market share of the IRL market? Does this vary significantly for any particular product class that you manufacture?
- 3.3 Do you manufacture any products other than IRLs? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to IRLs?
- 3.4 Please complete
- 3.5 Table 13A.2-5 to the best of your ability. If possible, please express revenue in both dollar amount and in percentage of total IRL sales. Additionally, please express shipments in both volume and percentage of all IRL shipments. Please indicate if you do not manufacture products in any given product class.

Table 13A.2-5 IRL Percent Revenue and Shipment Volumes by Product Class

IRL Product Class	2012 Revenue		2012 Shipments	
	\$	% of Total IRL Sales	Units	% of Total IRL Sales
Standard Spectrum, > 2.5 inches, ≥ 125 V				
Standard Spectrum, > 2.5 inches, < 125 V				
Standard Spectrum, ≤ 2.5 inches, ≥ 125 V				
Standard Spectrum, ≤ 2.5 inches, < 125 V				
Modified Spectrum, > 2.5 inches, ≥ 125 V				
Modified Spectrum, > 2.5 inches, < 125 V				
Modified Spectrum, ≤ 2.5 inches, ≥ 125 V				
Modified Spectrum, ≤ 2.5 inches, < 125 V				

4 MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how amended energy conservation standards would impact your company's markup structure and profitability.

DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. These include direct labor, direct materials, and overhead (which includes depreciation). The manufacturer markup is a multiplier applied to manufacturer production cost to cover non-production costs, such as selling, general, and administrative (SG&A) expenses and research and development (R&D) expenditures, as well as profit. *It does not reflect a "profit margin."* This is also sometimes referred to as "gross margin."

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

DOE estimated a markup of 1.58 for all IRLs.

- 4.1 Is the 1.58 markup representative of an average industry markup?
- 4.2 Please comment on the markup DOE calculated as compared to your company's markup for IRLs.
- 4.3 Do profit levels vary by product class or product line? If yes, please indicate why.

- 4.4 Because the market disruption caused by efficiency standards can alter the pricing of premium products, DOE is interested in understanding how margins currently change with efficiency. Within each product class, do markups vary by efficiency level? If yes, please provide information about the markups at higher efficiencies.
- 4.5 What factors besides efficiency affect the profitability of IRLs within a product class?
- 4.6 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 SHIPMENT PROJECTIONS

- 5.1 Have shipments of recently introduced products shown that they are popular with consumers? Please explain.
- 5.2 Do you expect characteristics of IRL lamps to change in response to amended standards? If so, please describe the potential changes to IRL characteristics.
- 5.3 Do you expect your market share of IRLs to change when amended energy conservation standards require compliance? If so, please describe the potential changes in market shares.

6 FINANCIAL PARAMETERS

Navigant Consulting, Inc. has developed a “strawman” model of the IRL industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. However, this public information might not be reflective of manufacturing at the IRL profit center. This section attempts to understand the financial parameters for IRL manufacturing and how your company’s financial situation could differ from the industry aggregate picture.

- 6.1 In order to accurately collect information about IRL manufacturing, please compare your financial parameters to the GRIM parameters tabulated below.

Table 13A.2-6 Financial Parameters for IRL Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	31.2%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.2%	
Working Capital	Current assets less current liabilities (percentage of revenues)	4.9%	
Net PPE	Net plant property and equipment (percentage of revenues)	18.2%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	17.9%	
R&D	Research and development expenses (percentage of revenues)	4.5%	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.5%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.4%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	63.4%	

Do any of the financial parameters in

6.2 Table 13A.2-6 change significantly based on product class? (See Table 13A.2-4 for a list of product classes.) Please describe any differences.

Do any of the financial parameters in

6.3 Table 13A.2-6 change for a particular subgroup of manufacturers? Please describe any differences.

6.4 How would you expect amended energy conservation standards to impact any of the financial parameters for the industry?

6.5 Can you please provide the breakdown in the total production costs for IRLs by the percentage for labor, materials, overhead, and depreciation by filling in Table 13A.2-7 below?

Table 13A.2-7 Breakdown of Total Production Costs for IRLs

Labor % of full production costs	Materials % of full production costs	Overhead % of full production costs	Depreciation % of full production costs

7 CONVERSION COSTS

DOE understands that amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing production lines. Understanding the nature and magnitude of the conversion costs is a critical part of the MIA. Depending on their magnitude, the conversion costs can have a substantial effect on the outputs used by DOE to evaluate the impact of amended energy conservation standards on the IRL industry. The MIA considers two types of conversion costs:

- *Capital conversion costs* are one-time investments in plant, property, and equipment (PPE) necessitated by amended energy conservation standards. These may be incremental additions to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- *Product conversion costs* are costs related to research, product development, testing, marketing and other costs for redesigning products necessitated by amended energy conservation standards.

Table 13A.2-1 shows the efficacy and typical characteristics of the representative lamp units. DOE asks a number of questions to understand the nature and magnitude of your expected capital and product conversion costs. Please refer to Table 13A.2-1 when considering your response to the following questions.

- 7.1 At your manufacturing facilities, would the design options you would choose to meet these efficacy levels be difficult to implement? If so, would your company modify the existing facility or develop a new facility?
- 7.2 Are there certain design options that would require relatively minor changes to existing products? Are there certain efficacy levels where the capital or product conversion costs significantly increase over the previous efficacy levels? Would your answer change for different product classes? Please describe these changes qualitatively.
- 7.3 For each of the product classes shown in Table 13A.2-4, which ELs could be achieved within existing platform designs and which would result in major product redesigns?
- 7.4 Please provide estimates for your capital conversion costs by product class in Table 13A.2-8 below. In the description column, DOE is interested in understanding the kinds of changes that would need to be implemented to production lines and production facilities at each efficacy level. Where applicable, please quantify the number and cost of new production equipment, molds, etc., that would be required to implement the specified design changes.
- 7.5 What product conversion costs would you expect to incur to achieve each of these efficacy levels for each product class? Please provide your estimates in Table 13A.2-8 below considering such expenses as product development expenses, prototyping, testing,

certification, and marketing. In the description column, please describe the assumptions behind the estimates provided.

Table 13A.2-8 Expected Product and Capital Conversion Costs for IRLs

Product Class	EL	Total Product Conversion Costs (\$)	Total Capital Conversion Costs (\$)	Description
Standard Spectrum, > 2.5 inches, < 125 V	Baseline			
	1			
	2			
	3			

8 CUMULATIVE REGULATORY BURDEN

Cumulative regulatory burden refers to the burden that industry faces from overlapping effects of new or revised DOE standards and/or other regulatory actions affecting the same product or industry.

- 8.1 Below is a list of regulations that could affect manufacturers of IRLs. Please provide any comments on the listed regulations and provide an estimate for your expected compliance cost.

Table 13A.2-9 Other Regulations Identified by DOE

Regulation	Estimated or Actual Effective Date(s)	Expected Expense for Compliance	Comments
DOE's Energy Conservation Standards for Other Products and Equipment (e.g. 2009 GSFL/IRL rule, etc.)			
International Energy Efficiency Standards			
Restriction of Hazardous Substances (RoHS)			
Others			

- 8.2 Are there any other recent or impending regulations that IRL manufacturers face (from DOE or otherwise)? If so, please identify the regulation, the corresponding effective dates, and your expected compliance cost.
- 8.3 Under what circumstances would you be able to coordinate any expenditure related to these other regulations with amended energy conservation standards?

9 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in IRL employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

- 9.1 Where are your IRL facilities that produce products for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's IRL manufacturing at each location by product class. Please also provide employment levels at each of these facilities.

Table 13A.2-10 IRL Manufacturing Facilities

Facility	Location	Product Types Manufactured	Employees	Annual Shipments
<i>Example</i>	<i>Jackson, TN</i>	Standard Spectrum, > 2.5 inches, < 125 V	<i>650</i>	<i>300,000 for Standard Spectrum, > 2.5 inches, < 125 V</i>
1				
2				
3				
4				
5				

- 9.2 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how and why they would change if higher efficacy levels were required.
- 9.3 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?
- 9.4 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

10 MANUFACTURING CAPACITY AND NON-U.S. SALES

- 10.1 How would amended energy conservation standards impact your company's manufacturing capacity?
- 10.2 For any design changes that would require new production equipment, please describe how much downtime would be required. What impact would downtime have on your

business? Are there any design changes that could not be implemented before the compliance date of the final rule for certain product classes?

- 10.3 What percentage of your company's IRLs sold within the United States is manufactured domestically?
- 10.4 What percentage of your U.S. production of IRLs is exported?
- 10.5 Are there any foreign companies with North American production facilities?
- 10.6 Would amended energy conservation standards impact your domestic vs. foreign manufacturing or sourcing decisions? Is there an efficacy level that would cause you to move existing domestic production facilities outside the U.S.?

11 IMPACT ON COMPETITION

Amended energy conservation standards can alter the competitive dynamics of the market. This can include prompting companies to enter or exit the market, or to merge. DOE and the Department of Justice are both interested in any potential reduction in competition that would result from an amended energy conservation standard.

- 11.1 How would industry competition change as a result of amended energy conservation standards? How would amended energy conservation standards affect *your* ability to compete in the marketplace? Would the effects on your company be different than others in the industry?

12 IMPACTS OF SMALL BUSINESSES

- 12.1 The Small Business Administration (SBA) denotes a small business in the IRL manufacturing industry as having less than 1,000 total employees, including the parent company and all subsidiaries.⁵ By this definition, is your company considered a small business?
- 12.2 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under amended energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.
- 12.3 To your knowledge, are there any small businesses for which the adoption of amended

⁵ DOE uses the small business size standards published on January 7, 2013, as amended, by the SBA to determine whether a company is a small business. To be categorized as a small business, an electric lamp manufacturer and its affiliates may employ a maximum of 1,000 employees. The 1,000 employee threshold includes all employees in a business's parent company and any other subsidiaries.

energy conservation standards would have a particularly severe impact? If so, why?

- 12.4 To your knowledge, are there any niche manufacturers or component manufacturers for which the adoption of amended energy conservation standards would have a particularly severe impact? If so, why?

**13A.3 SMALL MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR
GENERAL SERVICE FLUORESCENT LAMPS**

Summer 2013

The US Department of Energy (DOE) is conducting a manufacturer impact analysis (MIA) as part of the rulemaking process to amend energy conservation standards for general service fluorescent lamps (GSFLs). In this analysis, DOE uses publicly available information and information provided during interviews to assess possible impacts on manufacturers due to amended energy conservation standards. DOE began the rulemaking process with the publication of a framework document, followed by a publication of a preliminary analysis. Both can be found at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24. The GSFLs covered in this rulemaking are separated into product classes, based on lamp type and CCT range, as shown below.

Table 13A.3-1 Product Classes Under Consideration

Lamp Type	CCT Division
4-foot medium bipin	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K
2-foot U-shaped	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K
8-foot single pin slimline	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K
8-foot recessed double contact high output	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K
4-foot miniature bipin standard output	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K
4-foot miniature bipin high output	CCT $\leq$ 4500K
	CCT $>$ 4500K and $\leq$ 7000K

DOE is considering up to four energy efficacy levels for this GSFL rulemaking, including a baseline efficiency level. The table below presents the efficacy levels (ELs) under consideration for this rulemaking. In responding to this questionnaire, please refer to the ELs in the tables below. The table shows DOE's preliminary engineering results for each product class.

Table 13A.3-2 4-foot MBP (CCT $\leq$ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W)	Key Design/Technology Characteristics*	Proposed Efficacy Level (lm/W)
Baseline	32 W T8	89.2	Full wattage 800 series; initial lumens 2,900; 24,000 lifetime	No proposed level
EL 1	32 W T8	90.0	Full wattage improved 800 series; initial lumens 2,925; 21,000 hour lifetime	90.0
EL 2	25 W T8	93.0	Reduced wattage 800 series; initial lumens 2,475; 24,000 hour lifetime	93.0
	32 W T8	95.4	Full wattage high lumen 800 series; initial lumens 3,100; 24,000 hour lifetime	
	28 W T8	96.0	Reduced wattage 800 series; initial lumens 2,725; 24,000 hour lifetime	
EL 3	32 W T8	101.5	Full wattage high lumen improved 800 series; initial lumens 3,300; 24,000 hour lifetime	101.5

* Average rated lifetime based on 3 hour instant starts

Table 13A.3-3 8-foot Single Pin (SP) Slimline (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W)	Key Design/Technology Characteristics*	Proposed Efficacy Level (lm/w)
Baseline	59 W T8	96.5	Full wattage 800 series; 5,800 initial lumens; 24,000 hour lifetime	No proposed level
EL 1	59 W T8	98.2	Full wattage improved 800 series; 5,900 initial lumens; 24,000 hour lifetime	98.2
EL 2	59 W T8	99.0	Full wattage further improved 800 series; 5,950 initial lumens; 24,000 hour lifetime	99.0
	54 W T8	105.6	Reduced wattage 800 series; 5,700 initial lumens; 24,000 hour lifetime	
	50 W T8	108.0	Reduced wattage 800 series; 5,400 initial lumens; 24,000 hour lifetime	

* Average rated lifetime based on 3 hour instant starts

Table 13A.3-4 8-foot Recessed Double Contact (RDC) HO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W)	Key Design/Technology Characteristics*	Proposed Efficacy Level (lm/w)
Baseline	86 W T8	92	Modeled baseline; full wattage less efficient 700 series; 7,728 initial lumens; 18,000 hour lifetime	No proposed level
EL 1	86 W T8	95.2	Full wattage 700 series; 8,000 initial lumens; 18,000 hour lifetime	94.0
EL 2	86 W T8	97.6	Full wattage 800 series; 8,200 initial lumens; 18,000 hour lifetime	97.6

* Average rated lifetime based on 3 hour instant starts

Table 13A.3-5 4-foot T5 MiniBP SO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W) at 35 °C	Efficacy (lm/W) at 25 °C	Key Design/Technology Characteristics*, **	Proposed Efficacy Level (lm/w) at 25 °C
Baseline	28 W T5	94.6	86	Modeled baseline; full wattage less efficient 800 series; 2,630 initial lumens (2,391 at 25 °C); 30,000 hour lifetime	No proposed level
EL 1	28 W T5	104.3	93.5	Full wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 30,000 hour lifetime	93.5
EL 2	28 W T5	109.7	98.2	Full wattage improved 800 series; 3,050 initial lumens (2,730 at 25 °C); 30,000 hour lifetime	98.2
EL 3	26 W T5	115.0	100.0	Reduced wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 30,000 hour lifetime	100.0
	28 W T5	110.8	100.7	Full wattage further improved 800 series; 3,080 initial lumens (2,800 at 25 °C); 30,000 hour lifetime	
	25 W T5	116.0	104.0	Reduced wattage 800 series; 2,900 initial lumens (2,600 at 25 °C); 35,000 hour lifetime	

* Where lumen output at 25 °C is not provided in catalogs, lumen output is estimated as 10% lower than lumen output at 35 °C.

** Average rated lifetime based on 3 hour programmed starts

Table 13A.3-6 4-foot T5 MiniBP HO (CCT ≤ 4500K) Engineering Analysis

Level	Lamp Type	Efficacy (lm/W) at 35 °C	Efficacy (lm/W) at 25 °C	Key Design/Technology Characteristics*, **	Proposed Efficacy Level (lm/w) at 25 °C
Baseline	54 W T5	83.6	76	Modeled baseline; less efficient 800 series; 4,498 initial lumens (4,089 at 25 °C); 24,000 hour lifetime	No proposed level
EL 1	54 W T5	92.9	82.7	Full wattage 800 series; 5,000 initial lumens (4,450 at 25 °C); 25,000 hour lifetime	82.7
EL 2	54 W T5	97.2	88.4***	Full wattage improved 800 series; 5,173 initial lumens (4,703 at 25 °C); 45,000 hour lifetime	88.4
	49 W T5	102.0	90.8	Reduced wattage 800 series; 5,000 initial lumens (4,450 at 25 °C); 35,000 hour lifetime	
	47 W T5	102.1	91.9	Reduced wattage 800 series; 4,800 initial lumens (4,319 at 25 °C); 30,000 hour lifetime	

* Where lumen output at 25 °C is not provided in catalogs, lumen output is estimated as 10% lower than lumen output at 35 °C,

** Average rated lifetime based on 3 hour programmed starts

***The efficacy and initial lumens for this lamps are based on compliance values.

1 INTRODUCTION

- 1.1 Are you aware of DOE's ongoing rulemaking to establish new national minimum energy conservation standards for GSFL lamps? If you are not already in it, would you like to be added to DOE's email database for updates relating to this rulemaking?
- 1.2 We are assessing the impacts of a potential energy conservation standard on small businesses. Is your company a small business (defined as less than 1,000 employees by the US Small Business Administration (SBA), including all subsidiaries and parent companies, and employees in all countries where you operate)? Are any of these employees located in the US?
- 1.3 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under adopted energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.
- 1.4 To your knowledge, are there any small businesses for which the adoption of energy conservation standards would have a particularly severe impact? If so, why?

2 KEY ISSUES

- 2.1 In general, what are the key issues for your company regarding amended energy

conservation standards and this rulemaking?

Do any of these issues become particularly significant for a specific equipment class or at a specific efficiency level? Please reference Table 13A.3-1 through *sed on 3 hour programmed starts*

2.2 Table 13A.3-6.

3 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to GSFL production. However, the context surrounding plant operation and details of plant production and costs are not always readily available from public sources. DOE is interested in gaining a more nuanced understanding of these issues and invites you to provide these details confidentially. Understanding the organizational setting around the GSFL industry profit center will help DOE assess the probable future of GSFL manufacturing activity with and without amended energy conservation standards.

3.1 Do you have a parent company, and/or any subsidiaries relevant to the GSFL industry?

3.2 What is your company's approximate market share of the GSFL market? Does this vary significantly for any particular product class that you manufacture?

3.3 Do you manufacture any products other than GSFLs? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to GSFLs?

Please complete Table 13A.3-7 to the best of your ability. If possible, please express revenue in both dollar amount and in percentage of total GSFL sales. Additionally, please express shipments in both volume and percentage of all GSFL shipments. Please indicate if you do not manufacture products in any given product class.

Table 13A.3-7 GSFL Percent Revenue and Shipment Volumes by Product Class

GSFL Product Class	2012 Revenue		2012 Shipments	
	\$	% of Total GSFL Sales	Units	% of Total GSFL Sales
4-foot MBP $\leq$ 4,500 K				
4-foot MBP $>$ 4,500 K				
2-foot U-Shaped $\leq$ 4,500 K				
2-foot U-Shaped $>$ 4,500 K				
8-foot SP slimline $\leq$ 4,500 K				
8-foot SP slimline $>$ 4,500 K				
8-foot RDC HO $\leq$ 4,500 K				
8-foot RDC HO $>$ 4,500 K				
4-foot T5 MiniBP SO $\leq$ 4,500 K				
4-foot T5 MiniBP SO $>$ 4,500 K				
4-foot T5 MiniBP HO $\leq$ 4,500 K				
4-foot T5 MiniBP HO $>$ 4,500 K				

4 MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how amended energy conservation standards would impact your company's markup structure and profitability.

DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. These include direct labor, direct materials, and overhead (which includes depreciation). The manufacturer markup is a multiplier applied to manufacturer production cost to cover non-production costs, such as selling, general, and administrative (SG&A) expenses and research and development (R&D) expenditures, as well as profit. *It does not reflect a "profit margin."* This is also sometimes referred to as "gross margin."

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

DOE estimated a markup of 1.58 for all general service fluorescent lamps.

4.1 Is the 1.58 markup representative of an average industry markup?

- 4.2 Please comment on the markup DOE calculated compared to your company's markup for GSFLs.
- 4.3 Do profit levels vary by product class or product line? If yes, please indicate why.
- 4.4 Because the market disruption caused by efficiency standards can alter the pricing of premium products, DOE is interested in understanding how margins currently change with efficiency. Within each product class, do markups vary by efficiency level? If yes, please provide information about the markups at higher efficiencies.
- 4.5 What factors besides efficiency affect the profitability of GSFLs within a product class?
- 4.6 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 FINANCIAL PARAMETERS

Navigant Consulting, Inc. has developed a "strawman" model of the GSFL industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. However, this public information might not be reflective of manufacturing at the GSFL profit center. This section attempts to understand the financial parameters for GSFL manufacturing and how your company's financial situation could differ from the industry aggregate picture.

- 5.1 In order to accurately collect information about GSFL manufacturing, please compare your financial parameters to the GRIM parameters tabulated below.

Table 13A.3-8 Financial Parameters for GSFL Manufacturers

GRIM Input	Definition	Industry Estimated	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	31.2%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.2%	
Working Capital	Current assets less current liabilities (percentage of revenues)	4.9%	
Net PPE	Net plant property and equipment (percentage of revenues)	18.2%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	17.9%	
R&D	Research and development expenses (percentage of revenues)	4.5%	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.5%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.4%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	63.4%	

- 5.2 Do any of the financial parameters in **Error! Reference source not found.** change significantly based on product class (see Table 13A.3-1 for a list of product classes)? Please describe any differences.
- 5.3 Do any of the financial parameters in **Error! Reference source not found.** change for a particular subgroup of manufacturers? Please describe any differences.
- 5.4 How would you expect amended energy conservation standards to impact any of the financial parameters for the industry?
- 5.5 Can you please provide the breakdown in the total production costs for GSFLs by the percentage for labor, materials, overhead, and depreciation by filling in Table 13A.3-9 below?

Table 13A.3-9 Breakdown of Total Production Costs for GSFLs

Labor % of full production costs	Materials % of full production costs	Overhead % of full production costs	Depreciation % of full production costs

6 CONVERSION COSTS

DOE understands that amended energy conservation standards may cause your company to incur capital and product conversion costs to redesign existing products and make changes to existing

production lines. Understanding the nature and magnitude of the conversion costs is a critical part of the MIA. Depending on their magnitude, the conversion costs can have a substantial effect on the outputs used by DOE to evaluate the impact of amended energy conservation standards on the GSFL industry. The MIA considers two types of conversion costs:

- *Capital conversion costs* are one-time investments in plant, property, and equipment (PPE) necessitated by amended energy conservation standards. These may be incremental additions to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- *Product conversion costs* are costs related to research, product development, testing, marketing and other costs for redesigning products necessitated by amended energy conservation standards.

Table 13A.3-2 through *sed on 3 hour programmed starts*

Table 13A.3-6 show efficacy and typical characteristics of the representative lamp units. DOE asks a number of questions to understand the nature and magnitude of your expected capital and product conversion costs. Please refer to these tables when considering your response to the following questions.

- 6.1 At your manufacturing facilities, would the design options you would choose to meet these ELs be difficult to implement? If so, would your company modify the existing facility or develop a new facility?
- 6.2 Are there certain design options that would require relatively minor changes to existing products? Are there certain efficacy levels where the capital or product conversion costs significantly increase over the previous efficacy levels? Would your answer change for different product classes? Please describe these changes qualitatively.
- 6.3 For each of the product classes shown in Table 13A.3-1, which ELs could be achieved within existing platform designs and which would result in major product redesigns?

Please provide estimates for your capital conversion costs by product class in

- 6.4 Table 13A.3-10 below. In the description column, DOE is interested in understanding the kinds of changes that would need to be implemented to production lines and production facilities at each efficacy level. Where applicable, please quantify the number and cost of new production equipment, molds, etc., that would be required to implement the specified design changes.

What product conversion costs would you expect to incur to achieve each of these efficacy levels

for each product class? Please provide your estimates in

- 6.5 Table 13A.3-10 below considering, such expenses as product development, prototyping, testing, certification, and marketing. In the description column, please describe the assumptions behind the estimates provided.

Table 13A.3-10 Expected Product and Capital Conversion Costs for GSFLs

Product Class	EL	Total Product Conversion Costs (\$)	Total Capital Conversion Costs (\$)	Description
4-Foot Medium Bipin CCT ≤ 4500K	Baseline			
	1			
	2			
	3			
8-Foot Single Pin Slimline CCT ≤ 4500K	Baseline			
	1			
	2			
8-Foot Recessed Double Contact High Output CCT ≤ 4500K	Baseline			
	1			
	2			
4-Foot Miniature Bipin Standard Output CCT ≤ 4500K	Baseline			
	1			
	2			
	3			
4-Foot Miniature Bipin High Output CCT ≤ 4500K	Baseline			
	1			
	2			

7 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in GSFL employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

- 7.1 Where are your GSFL facilities that produce products for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's GSFL manufacturing at each location by product class. Please also provide employment levels at each of these facilities.

Table 13A.3-11 GSFL Manufacturing Facilities

Facility	Location	Product Types Manufactured	Employees	Annual Shipments
Example	Jackson, TN	4-foot MBP, T5 SO	650	300,000 for 4-foot MBP, 200,000 for T5 SO
1				
2				
3				
4				
5				

- 7.2 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how and why they would change if higher efficacy levels were required.
- 7.3 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?
- 7.4 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

13A.4 SMALL MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE FOR INCANDESCENT REFLECTOR LAMPS

Summer 2013

The U.S. Department of Energy (DOE) is conducting a manufacturer impact analysis (MIA) as part of the rulemaking process to amended energy conservation standards for incandescent reflector lamps (IRLs). In this analysis, DOE uses publicly available information and information provided during interviews to assess possible impacts on manufacturers due to amended energy conservation standards. DOE began the rulemaking process with the publication of a framework document, followed by a publication of a preliminary analysis. Both can be found at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/24. The IRLs covered in this rulemaking are separated into product classes, based on lamp type, lamp diameter, and voltage, as shown below.

Table 13A.4-1IRL Product Class Summary

Lamp Type	Diameter	Voltage
Standard Spectrum	> 2.5 inches	≥ 125 V
		< 125 V
	≤ 2.5 inches	≥ 125 V
		< 125 V
Modified Spectrum	> 2.5 inches	≥ 125 V
		< 125 V
	≤ 2.5 inches	≥ 125 V
		< 125 V

**Gray shading indicates a representative product class*

DOE is considering four energy efficacy levels for this IRL rulemaking, including a baseline efficiency level. The table below presents the efficacy levels (ELs) under consideration for this rulemaking. In responding to this questionnaire, please refer to the ELs in the table below. The table shows DOE's preliminary engineering results for each product class.

Table 13A.4-2 IRL Efficiency Level Summary

Level	Lamp Type	Certification Values			Lifetime (hrs)	Efficacy Level Equation (lm/w)	Key Design/ Technology Characteristics
		Watt	Lumens	Efficacy (lm/w)			
Baseline	60W PAR38	60W	1,070	17.8	1,500	$5.9P^{0.27}$	Halogen technology using higher efficiency reflector coating
EL 1	55W PAR38	56W	1,036	18.5	2,500	$6.2P^{0.27}$	Halogen infrared (HIR) technology
	55W PAR38	55W	1,018	18.5	4,200	$6.2P^{0.27}$	HIR technology using higher efficiency reflector coating
EL 2	50W PAR38	53W	1,044	19.7	3,000	$6.7P^{0.27}$	HIR technology using higher efficiency reflector coating
EL 3	45W PAR30	45W	981	21.8	3,000	$7.8P^{0.27}$	Advanced HIR technology using more advanced efficiency reflector coating

1 INTRODUCTION

- 1.1 Are you aware of DOE's ongoing rulemaking to establish amended national minimum energy conservation standards for IRL lamps? If you are not already in it, would you like to be added to DOE's email database for updates relating to this rulemaking?
- 1.2 We are assessing the impacts of a potential energy conservation standard on small businesses. Is your company a small business (defined as less than 1,000 employees by the US Small Business Administration (SBA), including all subsidiaries and parent companies, and employees in all countries where you operate)? Are any of these employees located in the US?
- 1.3 Are there any reasons that a small business manufacturer might be at a disadvantage relative to a larger business under adopted energy conservation standards? Please consider such factors as technical expertise, access to capital, bulk purchasing power for materials/components, engineering resources, and any other relevant issues.
- 1.4 To your knowledge, are there any small businesses for which the adoption of energy conservation standards would have a particularly severe impact? If so, why?

2 KEY ISSUES

- 2.1 In general, what are the key issues for your company regarding amended energy conservation standards and this rulemaking?
- 2.2 Do any of these issues become particularly significant for a specific equipment class or at a specific efficiency level? Please reference Table 13A.4-1 and Table 13A.4-2.

3 COMPANY OVERVIEW AND ORGANIZATIONAL CHARACTERISTICS

DOE is interested in understanding manufacturer impacts at the plant or profit center level directly pertinent to IRL production. However, the context surrounding plant operation and details of plant production and costs are not always readily available from public sources. DOE is interested in gaining a more nuanced understanding of these issues and invites you to provide these details confidentially. Understanding the organizational setting around the IRL industry profit center will help DOE assess the probable future of IRL manufacturing activity with and without amended energy conservation standards.

- 3.1 Do you have a parent company, and/or any subsidiaries relevant to the IRL industry?
- 3.2 What is your company's approximate market share of the IRL market? Does this vary significantly for any particular product class that you manufacture?
- 3.3 Do you manufacture any products other than IRLs? If so, what other products do you manufacture? What percentage of your total manufacturing revenue corresponds to IRLs?

- 3.4 Please complete Table 13A.4-3 to the best of your ability. If possible, please express revenue in both dollar amount and in percentage of total IRL sales. Additionally, please express shipments in both volume and percentage of all IRL shipments. Please indicate if you do not manufacture products in any given product class.

Table 13A.4-3 IRL Percent Revenue and Shipment Volumes by Product Class

IRL Product Class	2012 Revenue		2012 Shipments	
	\$	% of Total IRL Sales	Units	% of Total IRL Sales
Standard Spectrum, > 2.5 inches, ≥ 125 V				
Standard Spectrum, > 2.5 inches, < 125 V				
Standard Spectrum, ≤ 2.5 inches, ≥ 125 V				
Standard Spectrum, ≤ 2.5 inches, < 125 V				
Modified Spectrum, > 2.5 inches, ≥ 125 V				
Modified Spectrum, > 2.5 inches, < 125 V				
Modified Spectrum, ≤ 2.5 inches, ≥ 125 V				
Modified Spectrum, ≤ 2.5 inches, < 125 V				

4 MARKUPS AND PROFITABILITY

One of the primary objectives of the MIA is to assess the impact of amended energy conservation standards on industry profitability. In this section, DOE would like to understand the current markup structure of the industry and how amended energy conservation standards would impact your company's markup structure and profitability.

DOE defines manufacturer production cost as all direct costs associated with manufacturing a product. These include direct labor, direct materials, and overhead (which includes depreciation). The manufacturer markup is a multiplier applied to manufacturer production cost to cover non-production costs, such as selling, general, and administrative (SG&A) expenses and research and development (R&D) expenditures, as well as profit. *It does not reflect a "profit margin."* This is also sometimes referred to as "gross margin."

The manufacturer production cost times the manufacturer markup equals the manufacturer selling price. Manufacturer selling price is the price manufacturers charge their first customers, but *does not* include additional costs along the distribution channels.

DOE estimated a markup of 1.58 for all IRLs.

- 4.1 Is the 1.58 markup representative of an average industry markup?

- 4.2 Please comment on the markup DOE calculated as compared to your company's markup for IRLs.
- 4.3 Do profit levels vary by product class or product line? If yes, please indicate why.
- 4.4 Because the market disruption caused by efficiency standards can alter the pricing of premium products, DOE is interested in understanding how margins currently change with efficiency. Within each product class, do markups vary by efficiency level? If yes, please provide information about the markups at higher efficiencies.
- 4.5 What factors besides efficiency affect the profitability of IRLs within a product class?
- 4.6 Would you expect changes in your estimated profitability following an amended energy conservation standard? If so, please explain why.

5 FINANCIAL PARAMETERS

Navigant Consulting, Inc. has developed a "strawman" model of the IRL industry financial performance called the Government Regulatory Impact Model (GRIM) using publicly available data. However, this public information might not be reflective of manufacturing at the IRL profit center. This section attempts to understand the financial parameters for IRL manufacturing and how your company's financial situation could differ from the industry aggregate picture.

- 5.1 In order to accurately collect information about IRL manufacturing, please compare your financial parameters to the GRIM parameters tabulated below.

Table 13A.4-4 Financial Parameters for IRL Manufacturers

GRIM Input	Definition	Industry Estimated Value	Your Actual (If Significantly Different from DOE's Estimate)
Income Tax Rate	Corporate effective income tax paid (percentage of earnings before taxes, EBT)	31.2%	
Discount Rate	Weighted average cost of capital (inflation-adjusted weighted average of corporate cost of debt and return on equity)	9.2%	
Working Capital	Current assets less current liabilities (percentage of revenues)	4.9%	
Net PPE	Net plant property and equipment (percentage of revenues)	18.2%	
SG&A	Selling, general, and administrative expenses (percentage of revenues)	17.9%	
R&D	Research and development expenses (percentage of revenues)	4.5%	
Depreciation	Amortization of fixed assets (percentage of revenues)	3.5%	
Capital Expenditures	Outlay of cash to acquire or improve capital assets (percentage of revenues, not including acquisition or sale of business units)	3.4%	
Cost of Goods Sold	Includes material, labor, overhead, and depreciation (percentage of revenues)	63.4%	

- 5.2 Do any of the financial parameters in Table 13A.4-4 change significantly based on product class? (See Table 13A.4-1 for a list of product classes.) Please describe any differences.
- 5.3 Do any of the financial parameters in Table 13A.4-4 change for a particular subgroup of manufacturers? Please describe any differences.
- 5.4 How would you expect amended energy conservation standards to impact any of the financial parameters for the industry?
- 5.5 Can you please provide the breakdown in the total production costs for IRLs by the percentage for labor, materials, overhead, and depreciation by filling in Table 13A.4-5 below?

Table 13A.4-5 Breakdown of Total Production Costs for IRLs

Labor % of full production costs	Materials % of full production costs	Overhead % of full production costs	Depreciation % of full production costs

6 CONVERSION COSTS

DOE understands that amended energy conservation standards may cause your company to incur

capital and product conversion costs to redesign existing products and make changes to existing production lines. Understanding the nature and magnitude of the conversion costs is a critical part of the MIA. Depending on their magnitude, the conversion costs can have a substantial effect on the outputs used by DOE to evaluate the impact of amended energy conservation standards on the IRL industry. The MIA considers two types of conversion costs:

- *Capital conversion costs* are one-time investments in plant, property, and equipment (PPE) necessitated by amended energy conservation standards. These may be incremental additions to existing PPE or the replacement of existing PPE. Included are expenditures on buildings, equipment, and tooling.
- *Product conversion costs* are costs related to research, product development, testing, marketing and other costs for redesigning products necessitated by amended energy conservation standards.

Table 13A.4-2 shows the efficacy and typical characteristics of the representative lamp units. DOE asks a number of questions to understand the nature and magnitude of your expected capital and product conversion costs. Please refer to Table 13A.4-2 when considering your response to the following questions.

- 6.1 At your manufacturing facilities, would the design options you would choose to meet these efficacy levels be difficult to implement? If so, would your company modify the existing facility or develop a new facility?
- 6.2 Are there certain design options that would require relatively minor changes to existing products? Are there certain efficacy levels where the capital or product conversion costs significantly increase over the previous efficacy levels? Would your answer change for different product classes? Please describe these changes qualitatively.
- 6.3 For each of the product classes shown in Table 13A.4-1, which ELs could be achieved within existing platform designs and which would result in major product redesigns?

Please provide estimates for your capital conversion costs by product class in

- 6.4 Table 13A.4-6 below. In the description column, DOE is interested in understanding the kinds of changes that would need to be implemented to production lines and production facilities at each efficacy level. Where applicable, please quantify the number and cost of new production equipment, molds, etc., that would be required to implement the specified design changes.

What product conversion costs would you expect to incur to achieve each of these efficacy levels for each product class? Please provide your estimates in

- 6.5 Table 13A.4-6 below considering such expenses as product development expenses, prototyping, testing, certification, and marketing. In the description column, please

describe the assumptions behind the estimates provided.

Table 13A.4-6 Expected Product and Capital Conversion Costs for IRLs

Product Class	EL	Total Product Conversion Costs (\$)	Total Capital Conversion Costs (\$)	Description
Standard Spectrum, > 2.5 inches, < 125 V	Baseline			
	1			
	2			
	3			

7 DIRECT EMPLOYMENT IMPACT ASSESSMENT

The impact of amended energy conservation standards on employment is an important consideration in the rulemaking process. This section of the interview guide seeks to explore current trends in IRL employment and solicit manufacturer views on how domestic employment patterns might be affected by amended energy conservation standards.

- 7.1 Where are your IRL facilities that produce products for the United States located? What types of products are manufactured at each location? Please provide annual shipment figures for your company's IRL manufacturing at each location by product class. Please also provide employment levels at each of these facilities.

Table 13A.4-7 IRL Manufacturing Facilities

Facility	Location	Product Types Manufactured	Employees	Annual Shipments
Example	Jackson, TN	Standard Spectrum, > 2.5 inches, < 125 V	650	300,000 for Standard Spectrum, > 2.5 inches, < 125 V
1				
2				
3				
4				
5				

- 7.2 Would your domestic employment levels be expected to change significantly under amended energy conservation standards? If so, please explain how and why they would change if higher efficacy levels were required.
- 7.3 Would the workforce skills necessary under amended energy conservation standards require extensive retraining or replacement of employees at your manufacturing facilities?
- 7.4 Would amended energy conservation standards require extensive retraining of your service/field technicians? If so, could you expand on how your service infrastructure would be impacted in general as a result of amended energy conservation standards?

APPENDIX 13B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

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APPENDIX 13B. GOVERNMENT REGULATORY IMPACT MODEL OVERVIEW

13B.1 INTRODUCTION AND PURPOSE

The purpose of the Government Regulatory Impact Model (GRIM) is to help quantify the impacts of energy conservation standards and other regulations on manufacturers. The basic mode of analysis is to estimate the change in the value of the industry or manufacturers following a regulation or a series of regulations. The model structure also allows an analysis of multiple products with regulations taking effect over a period of time, and of multiple regulations on the same products.

Industry net present value is defined, for the purpose of this analysis, as the discounted sum of industry free cash flows plus a discounted terminal value. The model calculates the actual cash flows by year and then determines the present value of those cash flows both without an energy conservation standard (*i.e.*, the base case) and under different trial standard levels (TSLs) (*i.e.*, the standards case).

Output from the model consists of summary financial metrics, graphs of major variables, and, when appropriate, access to the complete cash flow calculation.

13B.2 GENERAL SERVICE FLUORESCENT LAMP AND INCANDESCENT REFLECTOR LAMP DESCRIPTION

DOE analyzed the impacts of standards on general service fluorescent lamp (GSFL) and incandescent reflector lamp (IRL) manufacturers. The basic structure of the GRIM is a standard annual cash flow analysis that uses manufacturer selling prices, manufacturing costs, a shipments forecast, and financial parameters as inputs and accepts a set of regulatory conditions as changes in costs and investments. The cash flow analysis is separated into two major blocks: income and cash flow. The income calculation determines net operating profit after taxes. The cash flow calculation converts net operating profit after taxes into an annual cash flow by including investment and non-cash items. The line items below relate to the GSFL and IRL manufacturers and are definitions of listed items on the printout of the output sheet (see section 13B.3).

- (1) **Revenues:** Annual revenues - computed by multiplying products' unit prices at each efficiency level by the appropriate manufacturer markup;
- (2) **Total Shipments:** The total covered units shipped;
- (3) **Material:** The portion of cost of goods sold (COGS) that includes materials;
- (4) **Labor:** The portion of COGS that includes direct labor, commissions, dismissal pay, bonuses, vacation, sick leave, social security contributions, fringe, and assembly labor up-time;
- (5) **Depreciation:** The portion of COGS that includes an allowance for the total amount of fixed assets used to produce that one unit;
- (6) **Overhead:** The portion of COGS that includes indirect labor, indirect material, energy use, maintenance, property taxes, and insurance related to assets;
- (7) **Standard SG&A:** Selling, general, and administrative costs are computed as a percentage of **Revenues (1)**;

- (8) R&D:** GRIM separately accounts for ordinary research and development (R&D) as a percentage of *Revenues (1)*;
- (9) Product Conversion Costs:** Product conversion costs are one-time investments in research, development, testing, marketing, and other costs focused on making product designs comply with amended energy conservation standards. The GRIM allocates these costs over the period between the standards' announcement and compliance dates;
- (10) Stranded Assets:** In the year the standard becomes effective, a one-time write-off of stranded assets is accounted for;
- (11) Earnings Before Interest and Taxes (EBIT):** Includes profits before deductions for interest paid and taxes;
- (12) Per Unit EBIT:** The average amount of *EBIT (11)* per covered unit shipped;
- (13) EBIT/Revenues:** *EBIT (11)* as a percentage of sales to compare with the industry's average reported in financial statements;
- (14) Taxes:** Taxes on *EBIT (11)* are calculated by multiplying the tax rate contained in the Discounted Cash Flow tab by *EBIT (11)*;
- (15) Net Operating Profits After Taxes (NOPAT):** Computed by subtracting *Taxes (14)* from *EBIT (11)*;
- (16) NOPAT repeated:** *NOPAT (15)* is repeated in the Statement of Cash Flows;
- (17) Depreciation repeated:** *Depreciation (5)* is added back in the Statement of Cash Flows because it is a non-cash expense;
- (18) Stranded Assets repeated:** *Stranded Assets (10)* is added back in the Statement of Cash Flows because it is a non-cash expense;
- (19) Change in Working Capital:** Change in cash tied up in accounts receivable, inventory, and other cash investments necessary to support operations is calculated by multiplying working capital (as a percentage of revenues) by the change in annual revenues;
- (20) Cash Flow From Operations:** Calculated by taking *NOPAT (16)*, adding back non-cash items such as *Depreciation (17)* and *Stranded Assets (18)*, and subtracting the *Change in Working Capital (19)*;
- (21) Ordinary Capital Expenditures:** Ordinary investments in property, plant, and equipment to maintain and replace existing production assets, computed as a percentage of *Revenues (1)*;
- (22) Capital Conversion Costs:** Capital conversion costs are one-time investments in property, plant, and equipment to adapt or change existing production facilities so that new product designs can be fabricated and assembled under amended regulations; the GRIM allocates these costs over the period between the standards' announcement and compliance dates;
- (23) Free Cash Flow:** Calculated by taking annual *Cash Flow From Operations (20)* and subtracting *Ordinary Capital Expenditures (21)* and *Capital Conversion Costs (22)*;
- (24) Free Cash Flow repeated:** *Free Cash Flow (23)* is repeated in the Discounted Cash Flow section;

(25) Terminal Value: Estimate of the continuing value of the industry after the analysis period. Computed by growing the **Free Cash Flow (24)** at the beginning of 2046 at a constant rate in perpetuity;

(26) Present Value Factor: Factor used to calculate an estimate of the present value of an amount to be received in the future;

(27) Discounted Cash Flow: **Free Cash Flow (23)** multiplied by the **Present Value Factor (26)**. For the end of 2046, the discounted cash flow includes the discounted **Terminal Value (25)**; and

Industry Value thru the end of 2046: The sum of **Discounted Cash Flows (27)**.

13B.3 GENERAL SERVICE FLUORESCENT LAMP AND INCANDESCENT REFLECTOR LAMP DETAILED CASH FLOW EXAMPLE

	Base Yr		Ancmt Yr	Std Yr		2017		2018		2019		2020		2021		2022	
<u>Industry Income Statement</u>	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2012	2013	2014	2015	2016	2017
1 Revenues	\$ 315.3	\$ 291.2	\$ 267.7	\$ 248.4	\$ 229.4	\$ 223.8	\$ 201.6	\$ 171.7	\$ 126.5	\$ 88.2	\$ 76.9	\$ 315.3	\$ 291.2	\$ 267.7	\$ 248.4	\$ 229.4	\$ 223.8
2 Total Shipments	50.272	46.263	42.349	39.123	35.946	30.767	27.647	23.480	17.251	11.984	10.403	50.272	46.263	42.349	39.123	35.946	30.767
3 - Materials	\$ 136.9	\$ 126.4	\$ 116.3	\$ 107.9	\$ 99.6	\$ 97.2	\$ 87.5	\$ 74.5	\$ 54.9	\$ 38.3	\$ 33.4	\$ 136.9	\$ 126.4	\$ 116.3	\$ 107.9	\$ 99.6	\$ 97.2
4 - Labor	\$ 47.7	\$ 44.1	\$ 40.5	\$ 37.6	\$ 34.7	\$ 33.9	\$ 30.5	\$ 26.0	\$ 19.1	\$ 13.3	\$ 11.6	\$ 47.7	\$ 44.1	\$ 40.5	\$ 37.6	\$ 34.7	\$ 33.9
5 - Depreciation	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1	\$ 7.3	\$ 6.2	\$ 4.6	\$ 3.2	\$ 2.8	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1
6 - Overhead	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1	\$ 7.3	\$ 6.2	\$ 4.6	\$ 3.2	\$ 2.8	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1
7 - Standard SG&A	\$ 56.4	\$ 52.1	\$ 47.9	\$ 44.5	\$ 41.1	\$ 40.1	\$ 36.1	\$ 30.7	\$ 22.6	\$ 15.8	\$ 13.8	\$ 56.4	\$ 52.1	\$ 47.9	\$ 44.5	\$ 41.1	\$ 40.1
8 - R&D	\$ 14.2	\$ 13.1	\$ 12.0	\$ 11.2	\$ 10.3	\$ 10.1	\$ 9.1	\$ 7.7	\$ 5.7	\$ 4.0	\$ 3.5	\$ 14.2	\$ 13.1	\$ 12.0	\$ 11.2	\$ 10.3	\$ 10.1
9 - Product Conversion Costs	\$ -	\$ -	\$ 1.2	\$ 2.1	\$ 2.7	\$ 0.1	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 1.2	\$ 2.1	\$ 2.7	\$ 0.1
10 - Stranded Assets	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 41.3	\$ 10.2	\$ 8.7	\$ 6.4	\$ 4.4	\$ 3.8	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 41.3
11 Earnings Before Interest and Taxes (EBIT)	\$ 37.2	\$ 34.4	\$ 30.4	\$ 27.3	\$ 24.4	\$ (15.0)	\$ 13.6	\$ 11.6	\$ 8.6	\$ 6.0	\$ 5.2	\$ 37.2	\$ 34.4	\$ 30.4	\$ 27.3	\$ 24.4	\$ (15.0)
12 Per Unit EBIT	\$ 0.7407	\$ 0.7433	\$ 0.7186	\$ 0.6968	\$ 0.6793	\$ (0.4882)	\$ 0.4927	\$ 0.4951	\$ 0.4979	\$ 0.5008	\$ 0.5042	\$ 0.7407	\$ 0.7433	\$ 0.7186	\$ 0.6968	\$ 0.6793	\$ (0.4882)
13 EBIT/Revenues	11.8%	11.8%	11.4%	11.0%	10.6%	-6.7%	6.8%	6.8%	6.8%	6.8%	6.8%	11.8%	11.8%	11.4%	11.0%	10.6%	-6.7%
14 - Taxes	\$ 11.6	\$ 10.7	\$ 9.5	\$ 8.5	\$ 7.6	\$ -	\$ 4.3	\$ 3.6	\$ 2.7	\$ 1.9	\$ 1.6	\$ 11.6	\$ 10.7	\$ 9.5	\$ 8.5	\$ 7.6	\$ -
15 Net Operating Profit after Taxes (NOPAT)	\$ 25.6	\$ 23.7	\$ 20.9	\$ 18.8	\$ 16.8	\$ (15.0)	\$ 9.4	\$ 8.0	\$ 5.9	\$ 4.1	\$ 3.6	\$ 25.6	\$ 23.7	\$ 20.9	\$ 18.8	\$ 16.8	\$ (15.0)
<u>Cash Flow Statement</u>																	
16 NOPAT	\$ 25.6	\$ 23.7	\$ 20.9	\$ 18.8	\$ 16.8	\$ (15.0)	\$ 9.4	\$ 8.0	\$ 5.9	\$ 4.1	\$ 3.6	\$ 25.6	\$ 23.7	\$ 20.9	\$ 18.8	\$ 16.8	\$ (15.0)
17 + Depreciation	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1	\$ 7.3	\$ 6.2	\$ 4.6	\$ 3.2	\$ 2.8	\$ 11.4	\$ 10.5	\$ 9.7	\$ 9.0	\$ 8.3	\$ 8.1
18 + Loss on Disposal of Stranded Assets	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 41.3	\$ 10.2	\$ 8.7	\$ 6.4	\$ 4.4	\$ 3.8	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 41.3
19 - Change in Working Capital	\$ -	\$ (3.3)	\$ (3.2)	\$ (2.6)	\$ (2.6)	\$ (0.8)	\$ (3.0)	\$ (4.1)	\$ (6.2)	\$ (5.3)	\$ (1.6)	\$ -	\$ (3.3)	\$ (3.2)	\$ (2.6)	\$ (2.6)	\$ (0.8)
20 Cash Flows from Operations	\$ 37.0	\$ 37.5	\$ 33.8	\$ 30.4	\$ 27.7	\$ 35.2	\$ 29.9	\$ 27.0	\$ 23.0	\$ 17.0	\$ 11.8	\$ 37.0	\$ 37.5	\$ 33.8	\$ 30.4	\$ 27.7	\$ 35.2
21 - Ordinary Capital Expenditures	\$ 7.9	\$ 7.3	\$ 6.7	\$ 6.2	\$ 5.7	\$ 5.6	\$ 5.0	\$ 4.3	\$ 3.2	\$ 2.2	\$ 1.9	\$ 7.9	\$ 7.3	\$ 6.7	\$ 6.2	\$ 5.7	\$ 5.6
22 - Capital Conversion Costs	\$ -	\$ -	\$ 13.1	\$ 22.9	\$ 29.4	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ 13.1	\$ 22.9	\$ 29.4	\$ -
23 Free Cash Flow	\$ 29.2	\$ 30.2	\$ 14.1	\$ 1.3	\$ (7.5)	\$ 29.6	\$ 24.9	\$ 22.7	\$ 19.9	\$ 14.8	\$ 9.9	\$ 29.2	\$ 30.2	\$ 14.1	\$ 1.3	\$ (7.5)	\$ 29.6
<u>Discounted Cash Flow</u>																	
24 Free Cash Flow	\$ 29.2	\$ 30.2	\$ 14.1	\$ 1.3	\$ (7.5)	\$ 29.6	\$ 24.9	\$ 22.7	\$ 19.9	\$ 14.8	\$ 9.9	\$ 29.2	\$ 30.2	\$ 14.1	\$ 1.3	\$ (7.5)	\$ 29.6
25 Terminal Value	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
26 Present Value Factor	0.000	1.000	0.916	0.839	0.768	0.703	0.644	0.590	0.540	0.495	0.453	0.000	1.000	0.916	0.839	0.768	0.703
27 Discounted Cash Flow	\$ -	\$ 30.2	\$ 12.9	\$ 1.1	\$ (5.7)	\$ 20.8	\$ 16.0	\$ 13.4	\$ 10.7	\$ 7.3	\$ 4.5	\$ -	\$ 30.2	\$ 12.9	\$ 1.1	\$ (5.7)	\$ 20.8
INPV at TSL 1 \$ 128.6																	

APPENDIX 13C. INDUSTRY NET PRESENT VALUE RESULTS FOR INCANDESCENT REFLECTOR LAMPS SHORTENED LIFETIME SENSITIVITY

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APPENDIX 13C. INDUSTRY NET PRESENT VALUE RESULTS FOR IRL SHORTENED LIFETIME SENSITIVITY

13C.1 INTRODUCTION

The purpose of this appendix is to display the impacts on industry net present value (INPV) of incandescent reflector (IRL) manufacturers when manufacturers choose to shorten the lifetime of certain lamps in order to meet the proposed efficacy levels. DOE recognizes that there is an inverse relationship between efficacy and lifetime for IRLs and is aware that to meet higher efficacy levels, manufacturers could choose to produce lamps with a shorter lifetime than the baseline lamp. Given that some manufacturers responded to the previous energy conservation standards for IRLs (hereafter the “2009 Lamps Rule”) by introducing IRLs with shorter lifetimes, DOE believes that this is a path manufacturers may take in response to higher efficacy standards proposed by today’s NOPR for IRLs. Therefore, DOE developed a shortened lifetime sensitivity analysis. DOE implemented a shortened lifetime sensitivity scenario into the national impact analysis by altering several inputs. First, DOE implemented a shorter lifetime for the baseline unit IRL. Second, DOE modeled a different distribution of IRL shipments between ELs and a different overall number of IRL shipments compared to the reference case scenario. Finally, DOE used the same manufacturer selling prices and end-user prices for IRLs that were used in the MIA.

In the shortened lifetime sensitivity scenario, DOE believes that manufacturers would incur substantially lower capital conversion costs than they would in the reference case scenario. As detailed in Table 13C.2.1 and Table 13C.2.2 below, DOE believes that IRL manufacturers would incur \$10.5 million in capital conversion costs at TSL 1 in the shortened lifetime sensitivity scenario (down from \$65.4 million at TSL 1 in the reference case scenario). This is because in the shortened lifetime sensitivity scenario, manufacturers would not have to invest in improved reflector coating technology, nor would they have to increase the capacity of their burner machines with HIR technology. DOE believes that manufacturers would face the same amount of product conversion costs in the shortened lifetime scenario as they would in the reference case scenario (\$6.1 million). Manufacturers would still incur research and development costs to redesign lamps in order to achieve lower lifetimes. They would also still face testing and certification costs for redesigned products. Overall, the change in capital conversion costs would change the impact that amended energy conservation standards would have on manufacturers’ INPV, cash flows, and direct employment. These impacts are detailed below.

13C.2 IMPACTS ON INDUSTRY NET PRESENT VALUE UNDER THE SHORTENED LIFETIME SENSITIVITY SCENARIO

DOE used the same methodology described in chapter 13 of the TSD to develop INPV results when the shortened lifetime sensitivity scenario is included. In the shortened lifetime sensitivity scenario, manufacturers could experience a much less severe impact on INPV. In this scenario, DOE estimates that the INPV for IRL manufacturers is \$176.0 million in 2012\$, the

same as in the reference case scenario. Under the proposed standards, DOE expects that IRL manufacturers may lose up to 8.5 percent of their INPV, which is approximately \$14.9 million in 2012\$, in the shortened lifetime sensitivity scenario compared to up to 29.5 percent of their INPV, which corresponds to \$51.8 million in 2012\$, in the reference case scenario. The INPV results with the shortened lifetime sensitivity scenario are presented below in Table 13C.2.1 and Table 13C.2.2.

Table 13C.2.1 Manufacturer Impact Analysis for Incandescent Reflector Lamps - Flat Markup and Shortened Lifetime Sensitivity Scenario

	Units	Base Case	Trial Standard Level
			1
INPV	(2012\$ millions)	176.0	166.3
Change in INPV	(2012\$ millions)	-	(9.8)
	(%)	-	-5.6%
Product Conversion Costs	(2012\$ millions)	-	6.1
Capital Conversion Costs	(2012\$ millions)	-	10.5
Total Investment Required	(2012\$ millions)	-	16.6

Table 13C.2.2 Manufacturer Impact Analysis for Incandescent Reflector Lamps - Preservation of Operating Profit Markup and Shortened Lifetime Sensitivity Scenario

	Units	Base Case	Trial Standard Level
			1
INPV	(2012\$ millions)	176.0	161.1
Change in INPV	(2012\$ millions)	-	(14.9)
	(%)	-	-8.5%
Product Conversion Costs	(2012\$ millions)	-	6.1
Capital Conversion Costs	(2012\$ millions)	-	10.5
Total Investment Required	(2012\$ millions)	-	16.6

13C.3 IMPACTS ON INDUSTRY NET CASH FLOW UNDER THE SHORTENED LIFETIME SENSITIVITY SCENARIO

DOE used the same methodology described in chapter 13 of the TSD to develop annual free cash-flow results when the shortened lifetime sensitivity scenario is included. While INPV is useful for evaluating the long-term effects of amended energy conservation standards, short-term changes in cash flow are also important indicators of the industry's financial situation. The smaller capital investments manufacturers would have to make in the shortened lifetime sensitivity scenario may not strain the industry's access to capital nearly as much as the more substantial conversion costs in the reference case scenario. The industry cash flow results with the shortened lifetime sensitivity scenario are presented below in Figure 13C.3.1 and Figure 13C.3.2.

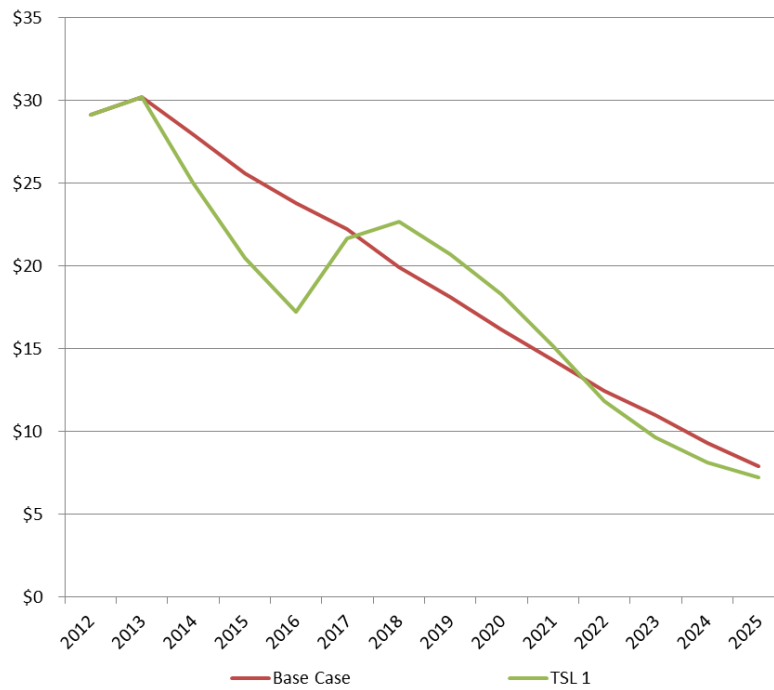


Figure 13C.3.1 Annual Industry Free Cash Flows for IRLs - Flat Markup and Shortened Lifetime Sensitivity Scenario

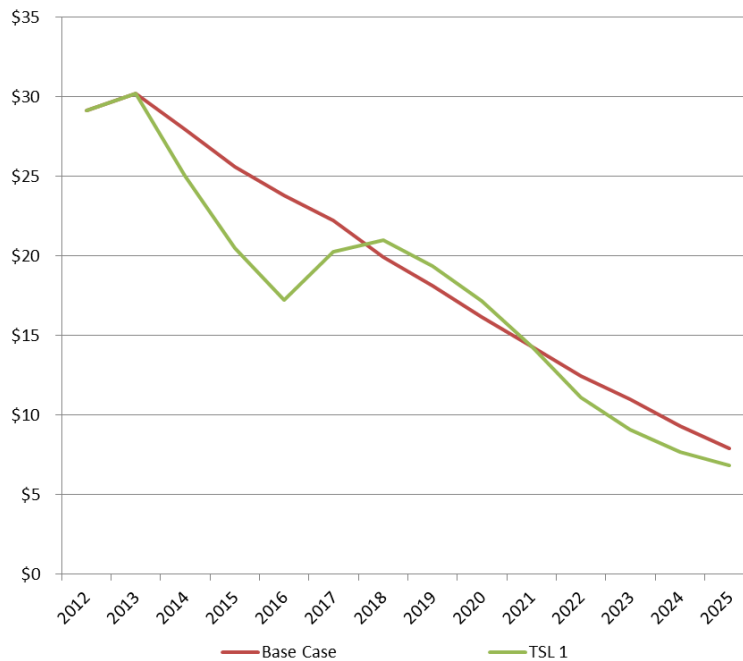


Figure 13C.3.2 Annual Industry Free Cash Flows for IRLs - Preservation of Operating Profit Markup and Shortened Lifetime Sensitivity Scenario

13C.4 IMPACTS ON EMPLOYMENT UNDER THE SHORTENED LIFETIME SENSITIVITY SCENARIO

DOE used the same methodology described in chapter 13 of the TSD to develop the direct employment impact results when the shortened lifetime sensitivity scenario is included. The lower bound of employment impacts is less severe in the shortened lifetime sensitivity scenario because lower conversion costs would make it less likely that manufacturers would exit the market. The employment results with the shortened lifetime sensitivity scenario are presented below in Table 13C.4.1

Table 13C.4.1 Potential Changes in the Total Number of Domestic IRL Production Workers in 2017 (Shortened Lifetime Sensitivity Scenario)

	Base Case	Trial Standard Level
		1
Total Number of Domestic Production Workers in 2017 (without changes in production locations)	308	343
Potential Changes in Domestic Production Workers in 2017*	-	35 - (103)

*DOE presents a range of potential employment impacts. Numbers in parentheses indicate negative numbers.

APPENDIX 15A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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APPENDIX 15A. SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866^a

15A.1 EXECUTIVE SUMMARY

Under Executive Order 12866, agencies are required, to the extent permitted by law, “to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.” The purpose of the “social cost of carbon” (SCC) estimates presented here is to allow agencies to incorporate the social benefits of reducing carbon dioxide (CO₂) emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions. The estimates are presented with an acknowledgement of the many uncertainties involved and with a clear understanding that they should be updated over time to reflect increasing knowledge of the science and economics of climate impacts.

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change.

This document presents a summary of the interagency process that developed these SCC estimates. Technical experts from numerous agencies met on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key model inputs and assumptions. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions grounded in the existing scientific and economic literatures. In this way, key uncertainties and model differences transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC from three integrated assessment models, at discount rates of 2.5, 3, and 5 percent. The fourth value, which represents the 95th percentile SCC estimate

^a Prepared by Interagency Working Group on Social Cost of Carbon, United States Government.

With participation by:

Council of Economic Advisers

Council on Environmental Quality

Department of Agriculture

Department of Commerce

Department of Energy

Department of Transportation

Environmental Protection Agency

National Economic Council

Office of Energy and Climate Change

Office of Management and Budget

Office of Science and Technology Policy

Department of the Treasury

across all three models at a 3 percent discount rate, is included to represent higher-than-expected impacts from temperature change further out in the tails of the SCC distribution.

Table 15A.1.1 Social Cost of CO₂, 2010 – 2050 (in 2007 dollars)

	<i>Discount Rate</i>			
	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

15A.2 MONETIZING CARBON DIOXIDE EMISSIONS

The SCC is an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. We report estimates of the SCC in dollars per metric ton of carbon dioxide throughout this document.^b

When attempting to assess the incremental economic impacts of carbon dioxide emissions, the analyst faces a number of serious challenges. A recent report from the National Academies of Science (NRC 2009) points out that any assessment will suffer from uncertainty, speculation, and lack of information about (1) future emissions of greenhouse gases, (2) the effects of past and future emissions on the climate system, (3) the impact of changes in climate on the physical and biological environment, and (4) the translation of these environmental impacts into economic damages. As a result, any effort to quantify and monetize the harms associated with climate change will raise serious questions of science, economics, and ethics and should be viewed as provisional.

Despite the serious limits of both quantification and monetization, SCC estimates can be useful in estimating the social benefits of reducing carbon dioxide emissions. Under Executive Order 12866, agencies are required, to the extent permitted by law, “to assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs.” The purpose of the SCC estimates presented here is to

^b In this document, we present all values of the SCC as the cost per metric ton of CO₂ emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO₂ and the mass of carbon is 3.67 (the molecular weight of CO₂ divided by the molecular weight of carbon = 44/12 = 3.67).

make it possible for agencies to incorporate the social benefits from reducing carbon dioxide emissions into cost-benefit analyses of regulatory actions that have small, or “marginal,” impacts on cumulative global emissions. Most federal regulatory actions can be expected to have marginal impacts on global emissions.

For such policies, the benefits from reduced (or costs from increased) emissions in any future year can be estimated by multiplying the change in emissions in that year by the SCC value appropriate for that year. The net present value of the benefits can then be calculated by multiplying each of these future benefits by an appropriate discount factor and summing across all affected years. This approach assumes that the marginal damages from increased emissions are constant for small departures from the baseline emissions path, an approximation that is reasonable for policies that have effects on emissions that are small relative to cumulative global carbon dioxide emissions. For policies that have a large (non-marginal) impact on global cumulative emissions, there is a separate question of whether the SCC is an appropriate tool for calculating the benefits of reduced emissions; we do not attempt to answer that question here.

An interagency group convened on a regular basis to consider public comments, explore the technical literature in relevant fields, and discuss key inputs and assumptions in order to generate SCC estimates. Agencies that actively participated in the interagency process include the Environmental Protection Agency, and the Departments of Agriculture, Commerce, Energy, Transportation, and Treasury. This process was convened by the Council of Economic Advisers and the Office of Management and Budget, with active participation and regular input from the Council on Environmental Quality, National Economic Council, Office of Energy and Climate Change, and Office of Science and Technology Policy. The main objective of this process was to develop a range of SCC values using a defensible set of input assumptions that are grounded in the existing literature. In this way, key uncertainties and model differences can more transparently and consistently inform the range of SCC estimates used in the rulemaking process.

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO₂ in 2015 and \$26 per ton of CO₂ in 2020. See Annex for the full range of annual SCC estimates from 2010 to 2050.

It is important to emphasize that the interagency process is committed to updating these estimates as the science and economic understanding of climate change and its impacts on society improves over time. Specifically, we have set a preliminary goal of revisiting the SCC values within two years or at such time as substantially updated models become available, and to continue to support research in this area. In the meantime, we will continue to explore the issues

raised in this document and consider public comments as part of the ongoing interagency process.

15A.3 SOCIAL COST OF CARBON VALUES USED IN PAST REGULATORY ANALYSES

To date, economic analyses for Federal regulations have used a wide range of values to estimate the benefits associated with reducing carbon dioxide emissions. In the final model year 2011 CAFE rule, the Department of Transportation (DOT) used both a “domestic” SCC value of \$2 per ton of CO₂ and a “global” SCC value of \$33 per ton of CO₂ for 2007 emission reductions (in 2007 dollars), increasing both values at 2.4 percent per year. It also included a sensitivity analysis at \$80 per ton of CO₂. A domestic SCC value is meant to reflect the value of damages in the United States resulting from a unit change in carbon dioxide emissions, while a global SCC value is meant to reflect the value of damages worldwide.

A 2008 regulation proposed by DOT assumed a domestic SCC value of \$7 per ton CO₂ (in 2006 dollars) for 2011 emission reductions (with a range of \$0-\$14 for sensitivity analysis), also increasing at 2.4 percent per year. A regulation finalized by DOE in October of 2008 used a domestic SCC range of \$0 to \$20 per ton CO₂ for 2007 emission reductions (in 2007 dollars). In addition, EPA’s 2008 Advance Notice of Proposed Rulemaking for Greenhouse Gases identified what it described as “very preliminary” SCC estimates subject to revision. EPA’s global mean values were \$68 and \$40 per ton CO₂ for discount rates of approximately 2 percent and 3 percent, respectively (in 2006 dollars for 2007 emissions).

In 2009, an interagency process was initiated to offer a preliminary assessment of how best to quantify the benefits from reducing carbon dioxide emissions. To ensure consistency in how benefits are evaluated across agencies, the Administration sought to develop a transparent and defensible method, specifically designed for the rulemaking process, to quantify avoided climate change damages from reduced CO₂ emissions. The interagency group did not undertake any original analysis. Instead, it combined SCC estimates from the existing literature to use as interim values until a more comprehensive analysis could be conducted.

The outcome of the preliminary assessment by the interagency group was a set of five interim values: global SCC estimates for 2007 (in 2006 dollars) of \$55, \$33, \$19, \$10, and \$5 per ton of CO₂. The \$33 and \$5 values represented model-weighted means of the published estimates produced from the most recently available versions of three integrated assessment models—DICE, PAGE, and FUND—at approximately 3 and 5 percent discount rates. The \$55 and \$10 values were derived by adjusting the published estimates for uncertainty in the discount rate (using factors developed by Newell and Pizer (2003)) at 3 and 5 percent discount rates, respectively. The \$19 value was chosen as a central value between the \$5 and \$33 per ton estimates. All of these values were assumed to increase at 3 percent annually to represent growth in incremental damages over time as the magnitude of climate change increases.

These interim values represent the first sustained interagency effort within the U.S. government to develop an SCC for use in regulatory analysis. The results of this preliminary effort were presented in several proposed and final rules and were offered for public comment in

connection with proposed rules, including the joint EPA-DOT fuel economy and CO₂ tailpipe emission proposed rules.

15A.4 APPROACH AND KEY ASSUMPTIONS

Since the release of the interim values, the interagency group has reconvened on a regular basis to generate improved SCC estimates. Specifically, the group has considered public comments and further explored the technical literature in relevant fields. This section details the several choices and assumptions that underlie the resulting estimates of the SCC.

It is important to recognize that a number of key uncertainties remain, and that current SCC estimates should be treated as provisional and revisable, since they will evolve with improved scientific and economic understanding. The interagency group also recognizes that the existing models are imperfect and incomplete. The National Academy of Science (2009) points out that there is tension between the goal of producing quantified estimates of the economic damages from an incremental ton of carbon and the limits of existing efforts to model these effects. Throughout this document, we highlight a number of concerns and problems that should be addressed by the research community, including research programs housed in many of the agencies participating in the interagency process to estimate the SCC.

The U.S. Government will periodically review and reconsider estimates of the SCC used for cost-benefit analyses to reflect increasing knowledge of the science and economics of climate impacts, as well as improvements in modeling. In this context, statements recognizing the limitations of the analysis and calling for further research take on exceptional significance. The interagency group offers the new SCC values with all due humility about the uncertainties embedded in them and with a sincere promise to continue work to improve them.

15A.4.1 Integrated Assessment Models

We rely on three integrated assessment models (IAMs) commonly used to estimate the SCC: the FUND, DICE, and PAGE models.^c These models are frequently cited in the peer-reviewed literature and used in the IPCC assessment. Each model is given equal weight in the SCC values developed through this process, bearing in mind their different limitations (discussed below).

These models are useful because they combine climate processes, economic growth, and feedbacks between the climate and the global economy into a single modeling framework. At the same time, they gain this advantage at the expense of a more detailed representation of the underlying climatic and economic systems. DICE, PAGE, and FUND all take stylized, reduced-

^c The DICE (Dynamic Integrated Climate and Economy) model by William Nordhaus evolved from a series of energy models and was first presented in 1990 (Nordhaus and Boyer 2000, Nordhaus 2008). The PAGE (Policy Analysis of the Greenhouse Effect) model was developed by Chris Hope in 1991 for use by European decision-makers in assessing the marginal impact of carbon emissions (Hope 2006, Hope 2008). The FUND (Climate Framework for Uncertainty, Negotiation, and Distribution) model, developed by Richard Tol in the early 1990s, originally to study international capital transfers in climate policy, is now widely used to study climate impacts (e.g., Tol 2002a, Tol 2002b, Anthoff et al. 2009, Tol 2009).

form approaches (see NRC 2009 for a more detailed discussion; see Nordhaus 2008 on the possible advantages of this approach). Other IAMs may better reflect the complexity of the science in their modeling frameworks but do not link physical impacts to economic damages. There is currently a limited amount of research linking climate impacts to economic damages, which makes this exercise even more difficult. Underlying the three IAMs selected for this exercise are a number of simplifying assumptions and judgments reflecting the various modelers' best attempts to synthesize the available scientific and economic research characterizing these relationships.

The three IAMs translate emissions into changes in atmospheric greenhouse concentrations, atmospheric concentrations into changes in temperature, and changes in temperature into economic damages. The emissions projections used in the models are based on specified socioeconomic (GDP and population) pathways. These emissions are translated into concentrations using the carbon cycle built into each model, and concentrations are translated into warming based on each model's simplified representation of the climate and a key parameter, climate sensitivity. Each model uses a different approach to translate warming into damages. Finally, transforming the stream of economic damages over time into a single value requires judgments about how to discount them.

Each model takes a slightly different approach to model how changes in emissions result in changes in economic damages. In PAGE, for example, the consumption-equivalent damages in each period are calculated as a fraction of GDP, depending on the temperature in that period relative to the pre-industrial average temperature in each region. In FUND, damages in each period also depend on the rate of temperature change from the prior period. In DICE, temperature affects both consumption and investment. We describe each model in greater detail here. In a later section, we discuss key gaps in how the models account for various scientific and economic processes (e.g. the probability of catastrophe, and the ability to adapt to climate change and the physical changes it causes).

The parameters and assumptions embedded in the three models vary widely. A key objective of the interagency process was to enable a consistent exploration of the three models while respecting the different approaches to quantifying damages taken by the key modelers in the field. An extensive review of the literature was conducted to select three sets of input parameters for these models: climate sensitivity, socioeconomic and emissions trajectories, and discount rates. A probability distribution for climate sensitivity was specified as an input into all three models. In addition, the interagency group used a range of scenarios for the socioeconomic parameters and a range of values for the discount rate. All other model features were left unchanged, relying on the model developers' best estimates and judgments. In DICE, these parameters are handled deterministically and represented by fixed constants; in PAGE, most parameters are represented by probability distributions. FUND was also run in a mode in which parameters were treated probabilistically.

The sensitivity of the results to other aspects of the models (e.g. the carbon cycle or damage function) is also important to explore in the context of future revisions to the SCC but has not been incorporated into these estimates. Areas for future research are highlighted at the end of this document.

The DICE Model

The DICE model is an optimal growth model based on a global production function with an extra stock variable (atmospheric carbon dioxide concentrations). Emission reductions are treated as analogous to investment in “natural capital.” By investing in natural capital today through reductions in emissions—implying reduced consumption—harmful effects of climate change can be avoided and future consumption thereby increased.

For purposes of estimating the SCC, carbon dioxide emissions are a function of global GDP and the carbon intensity of economic output, with the latter declining over time due to technological progress. The DICE damage function links global average temperature to the overall impact on the world economy. It varies quadratically with temperature change to capture the more rapid increase in damages expected to occur under more extreme climate change, and is calibrated to include the effects of warming on the production of market and nonmarket goods and services. It incorporates impacts on agriculture, coastal areas (due to sea level rise), “other vulnerable market sectors” (based primarily on changes in energy use), human health (based on climate-related diseases, such as malaria and dengue fever, and pollution), non-market amenities (based on outdoor recreation), and human settlements and ecosystems. The DICE damage function also includes the expected value of damages associated with low probability, high impact “catastrophic” climate change. This last component is calibrated based on a survey of experts (Nordhaus 1994). The expected value of these impacts is then added to the other market and non-market impacts mentioned above.

No structural components of the DICE model represent adaptation explicitly, though it is included implicitly through the choice of studies used to calibrate the aggregate damage function. For example, its agricultural impact estimates assume that farmers can adjust land use decisions in response to changing climate conditions, and its health impact estimates assume improvements in healthcare over time. In addition, the small impacts on forestry, water systems, construction, fisheries, and outdoor recreation imply optimistic and costless adaptation in these sectors (Nordhaus and Boyer, 2000; Warren et al., 2006). Costs of resettlement due to sea level rise are incorporated into damage estimates, but their magnitude is not clearly reported. Mastrandrea’s (2009) review concludes that “in general, DICE assumes very effective adaptation, and largely ignores adaptation costs.”

Note that the damage function in DICE has a somewhat different meaning from the damage functions in FUND and PAGE. Because GDP is endogenous in DICE and because damages in a given year reduce investment in that year, damages propagate forward in time and reduce GDP in future years. In contrast, GDP is exogenous in FUND and PAGE, so damages in any given year do not propagate forward.^d

^d Using the default assumptions in DICE 2007, this effect generates an approximately 25 percent increase in the SCC relative to damages calculated by fixing GDP. In DICE2007, the time path of GDP is endogenous. Specifically, the path of GDP depends on the rate of saving and level of abatement in each period chosen by the optimizing representative agent in the model. We made two modifications to DICE to make it consistent with EMF GDP trajectories (see next section): we assumed a fixed rate of savings of 20%, and we recalibrated the exogenous path of total factor productivity so that DICE would produce GDP projections in the absence of warming that exactly matched the EMF scenarios.

The PAGE Model

PAGE2002 (version 1.4epm) treats GDP growth as exogenous. It divides impacts into economic, non-economic, and catastrophic categories and calculates these impacts separately for eight geographic regions. Damages in each region are expressed as a fraction of output, where the fraction lost depends on the temperature change in each region. Damages are expressed as power functions of temperature change. The exponents of the damage function are the same in all regions but are treated as uncertain, with values ranging from 1 to 3 (instead of being fixed at 2 as in DICE).

PAGE2002 includes the consequences of catastrophic events in a separate damage sub-function. Unlike DICE, PAGE2002 models these events probabilistically. The probability of a “discontinuity” (i.e., a catastrophic event) is assumed to increase with temperature above a specified threshold. The threshold temperature, the rate at which the probability of experiencing a discontinuity increases above the threshold, and the magnitude of the resulting catastrophe are all modeled probabilistically.

Adaptation is explicitly included in PAGE. Impacts are assumed to occur for temperature increases above some tolerable level (2°C for developed countries and 0°C for developing countries for economic impacts, and 0°C for all regions for non-economic impacts), but adaptation is assumed to reduce these impacts. Default values in PAGE2002 assume that the developed countries can ultimately eliminate up to 90 percent of all economic impacts beyond the tolerable 2°C increase and that developing countries can eventually eliminate 50 percent of their economic impacts. All regions are assumed to be able to mitigate 25 percent of the non-economic impacts through adaptation (Hope 2006).

The FUND Model

Like PAGE, the FUND model treats GDP growth as exogenous. It includes separately calibrated damage functions for eight market and nonmarket sectors: agriculture, forestry, water, energy (based on heating and cooling demand), sea level rise (based on the value of land lost and the cost of protection), ecosystems, human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), and extreme weather. Each impact sector has a different functional form, and is calculated separately for sixteen geographic regions. In some impact sectors, the fraction of output lost or gained due to climate change depends not only on the absolute temperature change but also on the rate of temperature change and level of regional income.^e In the forestry and agricultural sectors, economic damages also depend on CO₂ concentrations.

Tol (2009) discusses impacts not included in FUND, noting that many are likely to have a relatively small effect on damage estimates (both positive and negative). However, he

^e In the deterministic version of FUND, the majority of damages are attributable to increased air conditioning demand, while reduced cold stress in Europe, North America, and Central and East Asia results in health benefits in those regions at low to moderate levels of warming (Warren et al., 2006).

characterizes several omitted impacts as “big unknowns”: for instance, extreme climate scenarios, biodiversity loss, and effects on economic development and political violence. With regard to potentially catastrophic events, he notes, “Exactly what would cause these sorts of changes or what effects they would have are not well-understood, although the chance of any one of them happening seems low. But they do have the potential to happen relatively quickly, and if they did, the costs could be substantial. Only a few studies of climate change have examined these issues.”

Adaptation is included both implicitly and explicitly in FUND. Explicit adaptation is seen in the agriculture and sea level rise sectors. Implicit adaptation is included in sectors such as energy and human health, where wealthier populations are assumed to be less vulnerable to climate impacts. For example, the damages to agriculture are the sum of three effects: (1) those due to the rate of temperature change (damages are always positive); (2) those due to the level of temperature change (damages can be positive or negative depending on region and temperature); and (3) those from CO₂ fertilization (damages are generally negative but diminishing to zero).

Adaptation is incorporated into FUND by allowing damages to be smaller if climate change happens more slowly. The combined effect of CO₂ fertilization in the agricultural sector, positive impacts to some regions from higher temperatures, and sufficiently slow increases in temperature across these sectors can result in negative economic damages from climate change.

Damage Functions

To generate revised SCC values, we rely on the IAM modelers’ current best judgments of how to represent the effects of climate change (represented by the increase in global-average surface temperature) on the consumption-equivalent value of both market and non-market goods (represented as a fraction of global GDP). We recognize that these representations are incomplete and highly uncertain. But given the paucity of data linking the physical impacts to economic damages, we were not able to identify a better way to translate changes in climate into net economic damages, short of launching our own research program.

The damage functions for the three IAMs are presented in Figure 15A.4.1 and Figure 15A.4.2, using the modeler’s default scenarios and mean input assumptions. There are significant differences between the three models both at lower (Figure 15A.4.2) and higher (Figure 15A.4.1) increases in global-average temperature.

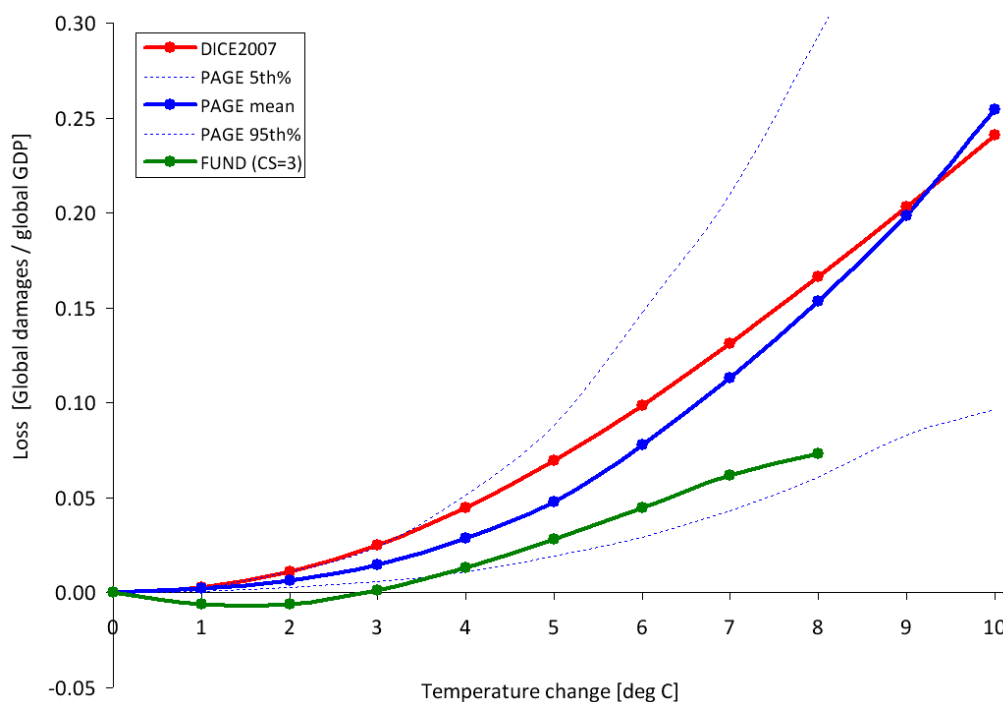


Figure 15A.4.1 Annual Consumption Loss as a Fraction of Global GDP in 2100 Due to an Increase in Annual Global Temperature in the DICE, FUND, and PAGE models^f

The lack of agreement among the models at lower temperature increases is underscored by the fact that the damages from FUND are well below the 5th percentile estimated by PAGE, while the damages estimated by DICE are roughly equal to the 95th percentile estimated by PAGE. This is significant because at higher discount rates we expect that a greater proportion of the SCC value is due to damages in years with lower temperature increases. For example, when the discount rate is 2.5 percent, about 45 percent of the 2010 SCC value in DICE is due to damages that occur in years when the temperature is less than or equal to 3 °C. This increases to approximately 55 percent and 80 percent at discount rates of 3 and 5 percent, respectively.

These differences underscore the need for a thorough review of damage functions—in particular, how the models incorporate adaptation, technological change, and catastrophic damages. Gaps in the literature make modifying these aspects of the models challenging, which highlights the need for additional research. As knowledge improves, the Federal government is committed to exploring how these (and other) models can be modified to incorporate more accurate estimates of damages.

^f The x-axis represents increases in annual, rather than equilibrium, temperature, while the y-axis represents the annual stream of benefits as a share of global GDP. Each specific combination of climate sensitivity, socioeconomic, and emissions parameters will produce a different realization of damages for each IAM. The damage functions represented in Figures 1A and 1B are the outcome of default assumptions. For instance, under alternate assumptions, the damages from FUND may cross from negative to positive at less than or greater than 3 °C.

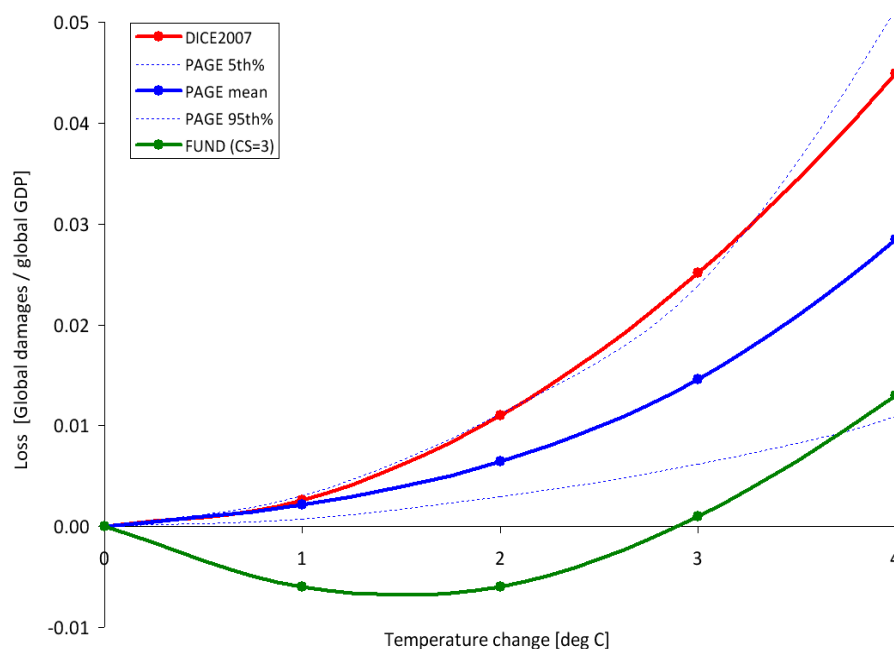


Figure 15A.4.2 Annual Consumption Loss for Lower Temperature Changes in DICE, FUND, and PAGE

15A.4.2 Global versus Domestic Measures of SCC

Because of the distinctive nature of the climate change problem, we center our current attention on a global measure of SCC. This approach is the same as that taken for the interim values, but it otherwise represents a departure from past practices, which tended to put greater emphasis on a domestic measure of SCC (limited to impacts of climate change experienced within U.S. borders). As a matter of law, consideration of both global and domestic values is generally permissible; the relevant statutory provisions are usually ambiguous and allow selection of either measure.^g

Global SCC

Under current OMB guidance contained in Circular A-4, analysis of economically significant proposed and final regulations from the domestic perspective is required, while analysis from the international perspective is optional. However, the climate change problem is highly unusual in at least two respects. First, it involves a global externality: emissions of most greenhouse gases contribute to damages around the world even when they are emitted in the United States. Consequently, to address the global nature of the problem, the SCC must incorporate the full (global) damages caused by GHG emissions. Second, climate change presents a problem that the United States alone cannot solve. Even if the United States were to reduce its greenhouse gas emissions to zero, that step would be far from enough to avoid

^g It is true that federal statutes are presumed not to have extraterritorial effect, in part to ensure that the laws of the United States respect the interests of foreign sovereigns. But use of a global measure for the SCC does not give extraterritorial effect to federal law and hence does not intrude on such interests.

substantial climate change. Other countries would also need to take action to reduce emissions if significant changes in the global climate are to be avoided. Emphasizing the need for a global solution to a global problem, the United States has been actively involved in seeking international agreements to reduce emissions and in encouraging other nations, including emerging major economies, to take significant steps to reduce emissions. When these considerations are taken as a whole, the interagency group concluded that a global measure of the benefits from reducing U.S. emissions is preferable.

When quantifying the damages associated with a change in emissions, a number of analysts (e.g., Anthoff, et al. 2009a) employ “equity weighting” to aggregate changes in consumption across regions. This weighting takes into account the relative reductions in wealth in different regions of the world. A per-capita loss of \$500 in GDP, for instance, is weighted more heavily in a country with a per-capita GDP of \$2,000 than in one with a per-capita GDP of \$40,000. The main argument for this approach is that a loss of \$500 in a poor country causes a greater reduction in utility or welfare than does the same loss in a wealthy nation. Notwithstanding the theoretical claims on behalf of equity weighting, the interagency group concluded that this approach would not be appropriate for estimating a SCC value used in domestic regulatory analysis.^h For this reason, the group concluded that using the global (rather than domestic) value, without equity weighting, is the appropriate approach.

Domestic SCC

As an empirical matter, the development of a domestic SCC is greatly complicated by the relatively few region- or country-specific estimates of the SCC in the literature. One potential source of estimates comes from the FUND model. The resulting estimates suggest that the ratio of domestic to global benefits of emission reductions varies with key parameter assumptions. For example, with a 2.5 or 3 percent discount rate, the U.S. benefit is about 7-10 percent of the global benefit, on average, across the scenarios analyzed. Alternatively, if the fraction of GDP lost due to climate change is assumed to be similar across countries, the domestic benefit would be proportional to the U.S. share of global GDP, which is currently about 23 percent.ⁱ

On the basis of this evidence, the interagency workgroup determined that a range of values from 7 to 23 percent should be used to adjust the global SCC to calculate domestic effects. Reported domestic values should use this range. It is recognized that these values are approximate, provisional, and highly speculative. There is no a priori reason why domestic benefits should be a constant fraction of net global damages over time. Further, FUND does not account for how damages in other regions could affect the United States (e.g., global migration, economic and political destabilization). If more accurate methods for calculating the domestic

^h It is plausible that a loss of \$X inflicts more serious harm on a poor nation than on a wealthy one, but development of the appropriate “equity weight” is challenging. Emissions reductions also impose costs, and hence a full account would have to consider that a given cost of emissions reductions imposes a greater utility or welfare loss on a poor nation than on a wealthy one. Even if equity weighting—for both the costs and benefits of emissions reductions—is appropriate when considering the utility or welfare effects of international action, the interagency group concluded that it should not be used in developing an SCC for use in regulatory policy at this time.

ⁱ Based on 2008 GDP (in current US dollars) from the *World Bank Development Indicators Report*.

SCC become available, the Federal government will examine these to determine whether to update its approach.

15A.4.3 Valuing Non-CO₂ Emissions

While CO₂ is the most prevalent greenhouse gas emitted into the atmosphere, the U.S. included five other greenhouse gases in its recent endangerment finding: methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The climate impact of these gases is commonly discussed in terms of their 100-year global warming potential (GWP). GWP measures the ability of different gases to trap heat in the atmosphere (i.e., radiative forcing per unit of mass) over a particular timeframe relative to CO₂. However, because these gases differ in both radiative forcing and atmospheric lifetimes, their relative damages are not constant over time. For example, because methane has a short lifetime, its impacts occur primarily in the near term and thus are not discounted as heavily as those caused by longer-lived gases. Impacts other than temperature change also vary across gases in ways that are not captured by GWP. For instance, CO₂ emissions, unlike methane and other greenhouse gases, contribute to ocean acidification. Likewise, damages from methane emissions are not offset by the positive effect of CO₂ fertilization. Thus, transforming gases into CO₂-equivalents using GWP, and then multiplying the carbon-equivalents by the SCC, would not result in accurate estimates of the social costs of non-CO₂ gases.

In light of these limitations, and the significant contributions of non-CO₂ emissions to climate change, further research is required to link non-CO₂ emissions to economic impacts. Such work would feed into efforts to develop a monetized value of reductions in non-CO₂ greenhouse gas emissions. As part of ongoing work to further improve the SCC estimates, the interagency group hopes to develop methods to value these other greenhouse gases. The goal is to develop these estimates by the time we issue revised SCC estimates for carbon dioxide emissions.

15A.4.4 Equilibrium Climate Sensitivity

Equilibrium climate sensitivity (ECS) is a key input parameter for the DICE, PAGE, and FUND models.^j It is defined as the long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO₂ concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm)). Uncertainties in this important parameter have received substantial attention in the peer-reviewed literature.

The most authoritative statement about equilibrium climate sensitivity appears in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC):

Basing our assessment on a combination of several independent lines of evidence...including observed climate change and the strength of known feedbacks simulated in [global climate

^j The equilibrium climate sensitivity includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et al. 2007).

models], we conclude that the global mean equilibrium warming for doubling CO₂, or ‘equilibrium climate sensitivity’, is likely to lie in the range 2 °C to 4.5 °C, with a most likely value of about 3 °C. Equilibrium climate sensitivity is very likely larger than 1.5 °C.^k

For fundamental physical reasons as well as data limitations, values substantially higher than 4.5 °C still cannot be excluded, but agreement with observations and proxy data is generally worse for those high values than for values in the 2 °C to 4.5 °C range. (Meehl et al., 2007, p 799)

After consulting with several lead authors of this chapter of the IPCC report, the interagency workgroup selected four candidate probability distributions and calibrated them to be consistent with the above statement: Roe and Baker (2007), log-normal, gamma, and Weibull. Table 15A.4.1 included below gives summary statistics for the four calibrated distributions.

Table 15A.4.1 Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5 th percentile	1.72	1.49	1.37	1.13
10 th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50 th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90 th percentile	5.86	5.14	4.93	4.69
95 th percentile	7.14	5.97	5.59	5.17

Each distribution was calibrated by applying three constraints from the IPCC:

- (1) a median equal to 3°C, to reflect the judgment of “a most likely value of about 3 °C”;^l
- (2) two-thirds probability that the equilibrium climate sensitivity lies between 2 and 4.5 °C; and
- (3) zero probability that it is less than 0°C or greater than 10°C (see Hegerl et al. 2006, p. 721).

^k This is in accord with the judgment that it “is likely to lie in the range 2 °C to 4.5 °C” and the IPCC definition of “likely” as greater than 66 percent probability (Le Treut et al.2007). “Very likely” indicates a greater than 90 percent probability.

^l Strictly speaking, “most likely” refers to the mode of a distribution rather than the median, but common usage would allow the mode, median, or mean to serve as candidates for the central or “most likely” value and the IPCC report is not specific on this point. For the distributions we considered, the median was between the mode and the mean. For the Roe and Baker distribution, setting the median equal to 3°C, rather than the mode or mean, gave a 95th percentile that is more consistent with IPCC judgments and the literature. For example, setting the mean and mode equal to 3°C produced 95th percentiles of 5.6 and 8.6 °C, respectively, which are in the lower and upper end of the range in the literature. Finally, the median is closer to 3°C than is the mode for the truncated distributions selected by the IPCC (Hegerl, et al., 2006); the average median is 3.1 °C and the average mode is 2.3 °C, which is most consistent with a Roe and Baker distribution with the median set equal to 3 °C.

We selected the calibrated Roe and Baker distribution from the four candidates for two reasons. First, the Roe and Baker distribution is the only one of the four that is based on a theoretical understanding of the response of the climate system to increased greenhouse gas concentrations (Roe and Baker 2007, Roe 2008). In contrast, the other three distributions are mathematical functions that are arbitrarily chosen based on simplicity, convenience, and general shape. The Roe and Baker distribution results from three assumptions about climate response: (1) absent feedback effects, the equilibrium climate sensitivity is equal to 1.2 °C; (2) feedback factors are proportional to the change in surface temperature; and (3) uncertainties in feedback factors are normally distributed. There is widespread agreement on the first point and the second and third points are common assumptions.

Second, the calibrated Roe and Baker distribution better reflects the IPCC judgment that “values substantially higher than 4.5°C still cannot be excluded.” Although the IPCC made no quantitative judgment, the 95th percentile of the calibrated Roe & Baker distribution (7.1 °C) is much closer to the mean and the median (7.2 °C) of the 95th percentiles of 21 previous studies summarized by Newbold and Daigneault (2009). It is also closer to the mean (7.5 °C) and median (7.9 °C) of the nine truncated distributions examined by the IPCC (Hegerl, et al., 2006) than are the 95th percentiles of the three other calibrated distributions (5.2-6.0 °C).

Finally, we note the IPCC judgment that the equilibrium climate sensitivity “is very likely larger than 1.5°C.” Although the calibrated Roe & Baker distribution, for which the probability of equilibrium climate sensitivity being greater than 1.5°C is almost 99 percent, is not inconsistent with the IPCC definition of “very likely” as “greater than 90 percent probability,” it reflects a greater degree of certainty about very low values of ECS than was expressed by the IPCC.

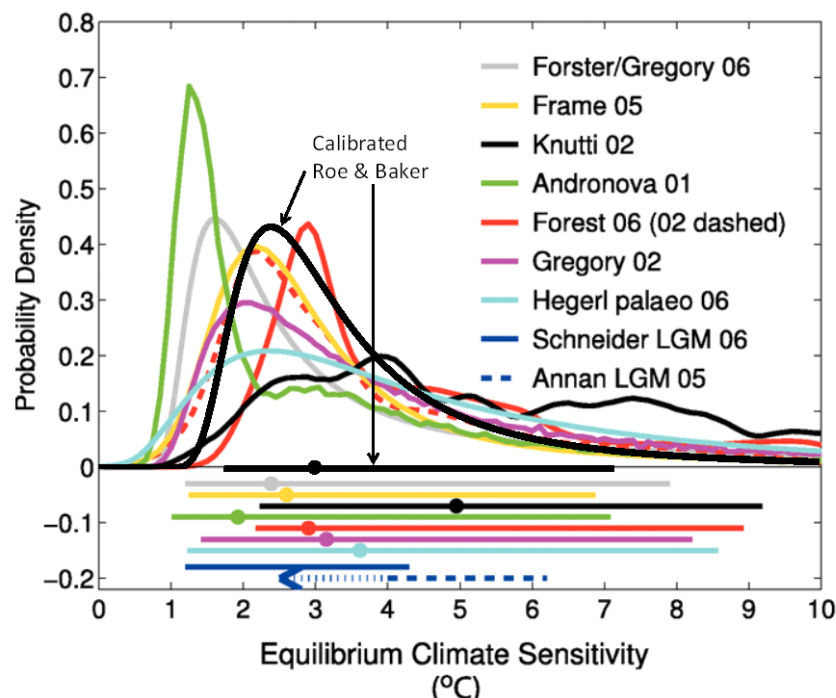


Figure 15A.4.3 Estimates of the Probability Density Function for Equilibrium Climate Sensitivity (°C)

To show how the calibrated Roe and Baker distribution compares to different estimates of the probability distribution function of equilibrium climate sensitivity in the empirical literature, Figure 15A.4.3 (above) overlays it on Figure 9.20 from the IPCC Fourth Assessment Report. These functions are scaled to integrate to unity between 0 °C and 10 °C. The horizontal bars show the respective 5 percent to 95 percent ranges; dots indicate the median estimate.^m

15A.4.5 Socioeconomic and Emissions Trajectories

Another key issue considered by the interagency group is how to select the set of socioeconomic and emissions parameters for use in PAGE, DICE, and FUND. Socioeconomic pathways are closely tied to climate damages because, all else equal, more and wealthier people tend to emit more greenhouse gases and also have a higher (absolute) willingness to pay to avoid climate disruptions. For this reason, we consider how to model several input parameters in tandem: GDP, population, CO₂ emissions, and non-CO₂ radiative forcing. A wide variety of scenarios have been developed and used for climate change policy simulations (e.g., SRES 2000, CCSP 2007, EMF 2009). In determining which scenarios are appropriate for inclusion, we aimed to select scenarios that span most of the plausible ranges of outcomes for these variables.

To accomplish this task in a transparent way, we decided to rely on the recent Stanford Energy Modeling Forum exercise, EMF-22. EMF-22 uses ten well-recognized models to evaluate substantial, coordinated global action to meet specific stabilization targets. A key advantage of relying on these data is that GDP, population, and emission trajectories are internally consistent for each model and scenario evaluated. The EMF-22 modeling effort also is preferable to the IPCC SRES due to their age (SRES were developed in 1997) and the fact that 3 of 4 of the SRES scenarios are now extreme outliers in one or more variables. Although the EMF-22 scenarios have not undergone the same level of scrutiny as the SRES scenarios, they are recent, peer-reviewed, published, and publicly available.

To estimate the SCC for use in evaluating domestic policies that will have a small effect on global cumulative emissions, we use socioeconomic and emission trajectories that span a range of plausible scenarios. Five trajectories were selected from EMF-22 (see Table 15A.4.2 below). Four of these represent potential business-as-usual (BAU) growth in population, wealth, and emissions and are associated with CO₂ (only) concentrations ranging from 612 to 889 ppm in 2100. One represents an emissions pathway that achieves stabilization at 550 ppm CO₂e (i.e., CO₂-only concentrations of 425 – 484 ppm or a radiative forcing of 3.7 W/m²) in 2100, a lower-than-BAU trajectory.ⁿ Out of the 10 models included in the EMF-22 exercise, we

^m The estimates based on instrumental data are from Andronova and Schlesinger (2001), Forest et al. (2002; dashed line, anthropogenic forcings only), Forest et al. (2006; solid line, anthropogenic and natural forcings), Gregory et al. (2002a), Knutti et al. (2002), Frame et al. (2005), and Forster and Gregory (2006). Hegerl et al. (2006) are based on multiple palaeoclimatic reconstructions of north hemisphere mean temperatures over the last 700 years. Also shown are the 5-95 percent approximate ranges for two estimates from the last glacial maximum (dashed, Annan et al. 2005; solid, Schneider von Deimling et al. 2006), which are based on models with different structural properties.

ⁿ Such an emissions path would be consistent with widespread action by countries to mitigate GHG emissions, though it could also result from technological advances. It was chosen because it represents the most stringent case analyzed by the EMF-22 where all the models converge: a 550 ppm, not to exceed, full participation scenario.

selected the trajectories used by MiniCAM, MESSAGE, IMAGE, and the optimistic scenario from MERGE. For the BAU pathways, we used the GDP, population, and emission trajectories from each of these four models. For the 550 ppm CO₂e scenario, we averaged the GDP, population, and emission trajectories implied by these same four models.

Table 15A.4.2 Socioeconomic and Emissions Projections from Select EMF-22 Reference Scenarios

Reference Fossil and Industrial CO₂ Emissions (GtCO₂/yr)						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	26.6	31.9	36.9	40.0	45.3	60.1
MERGE Optimistic	24.6	31.5	37.6	45.1	66.5	117.9
MESSAGE	26.8	29.2	37.6	42.1	43.5	42.7
MiniCAM	26.5	31.8	38.0	45.1	57.8	80.5
550 ppm average	26.2	31.1	33.2	32.4	20.0	12.8

Reference GDP (using market exchange rates in trillion 2005\$)^o						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	38.6	53.0	73.5	97.2	156.3	396.6
MERGE Optimistic	36.3	45.9	59.7	76.8	122.7	268.0
MESSAGE	38.1	52.3	69.4	91.4	153.7	334.9
MiniCAM	36.1	47.4	60.8	78.9	125.7	369.5
550 ppm average	37.1	49.6	65.6	85.5	137.4	337.9

Global Population (billions)						
EMF – 22 Based Scenarios	2000	2010	2020	2030	2050	2100
IMAGE	6.1	6.9	7.6	8.2	9.0	9.1
MERGE Optimistic	6.0	6.8	7.5	8.2	9.0	9.7
MESSAGE	6.1	6.9	7.7	8.4	9.4	10.4
MiniCAM	6.0	6.8	7.5	8.1	8.8	8.7
550 ppm average	6.1	6.8	7.6	8.2	8.7	9.1

We explore how sensitive the SCC is to various assumptions about how the future will evolve without prejudging what is likely to occur. The interagency group considered formally

^o While the EMF-22 models used market exchange rates (MER) to calculate global GDP, it is also possible to use purchasing power parity (PPP). PPP takes into account the different price levels across countries, so it more accurately describes relative standards of living across countries. MERs tend to make low-income countries appear poorer than they actually are. Because many models assume convergence in per capita income over time, use of MER-adjusted GDP gives rise to projections of higher economic growth in low income countries. There is an ongoing debate about how much this will affect estimated climate impacts. Critics of the use of MER argue that it leads to overstated economic growth and hence a significant upward bias in projections of greenhouse gas emissions, and unrealistically high future temperatures (e.g., Castles and Henderson 2003). Others argue that convergence of the emissions-intensity gap across countries at least partially offset the overstated income gap so that differences in exchange rates have less of an effect on emissions (Holtmark and Alfsen, 2005; Tol, 2006). Nordhaus (2007b) argues that the ideal approach is to use superlative PPP accounts (i.e., using cross-sectional PPP measures for relative incomes and outputs and national accounts price and quantity indexes for time-series extrapolations). However, he notes that it important to keep this debate in perspective; it is by no means clear that exchange-rate-conversion issues are as important as uncertainties about population, technological change, or the many geophysical uncertainties.

assigning probability weights to different states of the world, but this proved challenging to do in an analytically rigorous way given the dearth of information on the likelihood of a full range of future socioeconomic pathways.

There are a number of caveats. First, EMF BAU scenarios represent the modelers' judgment of the most likely pathway absent mitigation policies to reduce greenhouse gas emissions, rather than the wider range of possible outcomes. Nevertheless, these views of the most likely outcome span a wide range, from the more optimistic (e.g. abundant low-cost, low-carbon energy) to more pessimistic (e.g. constraints on the availability of nuclear and renewables).^p Second, the socioeconomic trajectories associated with a 550 ppm CO₂e concentration scenario are not derived from an assessment of what policy is optimal from a benefit-cost standpoint. Rather, it is indicative of one possible future outcome. The emission trajectories underlying some BAU scenarios (e.g. MESSAGE's 612 ppm) also are consistent with some modest policy action to address climate change.^q We chose not to include socioeconomic trajectories that achieve even lower GHG concentrations at this time, given the difficulty many models had in converging to meet these targets.

For comparison purposes, the Energy Information Agency in its 2009 Annual Energy Outlook projected that global carbon dioxide emissions will grow to 30.8, 35.6, and 40.4 gigatons in 2010, 2020, and 2030, respectively, while world GDP is projected to be \$51.8, \$71.0 and \$93.9 trillion (in 2005 dollars using market exchange rates) in 2010, 2020, and 2030, respectively. These projections are consistent with one or more EMF-22 scenarios. Likewise, the United Nations' 2008 Population Prospect projects population will grow from 6.1 billion people in 2000 to 9.1 billion people in 2050, which is close to the population trajectories for the IMAGE, MiniCAM, and MERGE models.

In addition to fossil and industrial CO₂ emissions, each EMF scenario provides projections of methane, nitrous oxide, fluorinated greenhouse gases, and net land use CO₂ emissions out to 2100. These assumptions also are used in the three models while retaining the default radiative forcings due to other factors (e.g. aerosols and other gases). See the Annex for greater detail.

15A.4.6 Discount Rate

The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law. Although it is well understood that the discount rate has a large influence on the current value of future damages, there is no consensus about what rates to use in this context. Because carbon dioxide emissions are long-lived, subsequent damages occur over many years. In calculating the

^p For instance, in the MESSAGE model's reference case total primary energy production from nuclear, biomass, and non-biomass renewables is projected to increase from about 15 percent of total primary energy in 2000 to 54 percent in 2100. In comparison, the MiniCAM reference case shows 10 percent in 2000 and 21 percent in 2100.

^q For example, MiniCAM projects if all non-US OECD countries reduce CO₂ emissions to 83 percent below 2005 levels by 2050 (per the G-8 agreement) but all other countries continue along a BAU path CO₂ concentrations in 2100 would drop from 794 ppmv in its reference case to 762 ppmv.

SCC, we first estimate the future damages to agriculture, human health, and other market and non-market sectors from an additional unit of carbon dioxide emitted in a particular year in terms of reduced consumption (or consumption equivalents) due to the impacts of elevated temperatures, as represented in each of the three IAMs. Then we discount the stream of future damages to its present value in the year when the additional unit of emissions was released using the selected discount rate, which is intended to reflect society's marginal rate of substitution between consumption in different time periods.

For rules with both intra- and intergenerational effects, agencies traditionally employ constant discount rates of both 3 percent and 7 percent in accordance with OMB Circular A-4. As Circular A-4 acknowledges, however, the choice of discount rate for intergenerational problems raises distinctive problems and presents considerable challenges. After reviewing those challenges, Circular A-4 states, “If your rule will have important intergenerational benefits or costs you might consider a further sensitivity analysis using a lower but positive discount rate in addition to calculating net benefits using discount rates of 3 and 7 percent.” For the specific purpose of developing the SCC, we adapt and revise that approach here.

Arrow et al. (1996) outlined two main approaches to determine the discount rate for climate change analysis, which they labeled “descriptive” and “prescriptive.” The descriptive approach reflects a positive (non-normative) perspective based on observations of people’s actual choices—e.g., savings versus consumption decisions over time, and allocations of savings among more and less risky investments. Advocates of this approach generally call for inferring the discount rate from market rates of return “because of a lack of justification for choosing a social welfare function that is any different than what decision makers [individuals] actually use” (Arrow et al. 1996).

One theoretical foundation for the cost-benefit analyses in which the social cost of carbon will be used—the Kaldor-Hicks potential-compensation test—also suggests that market rates should be used to discount future benefits and costs, because it is the market interest rate that would govern the returns potentially set aside today to compensate future individuals for climate damages that they bear (e.g., Just et al. 2004). As some have noted, the word “potentially” is an important qualification; there is no assurance that such returns will actually be set aside to provide compensation, and the very idea of compensation is difficult to define in the intergenerational context. On the other hand, societies provide compensation to future generations through investments in human capital and the resulting increase in knowledge, as well as infrastructure and other physical capital.

The prescriptive approach specifies a social welfare function that formalizes the normative judgments that the decision-maker wants explicitly to incorporate into the policy evaluation—e.g., how inter-personal comparisons of utility should be made, and how the welfare of future generations should be weighed against that of the present generation. Ramsey (1928), for example, has argued that it is “ethically indefensible” to apply a positive pure rate of time preference to discount values across generations, and many agree with this view.

Other concerns also motivate making adjustments to descriptive discount rates. In particular, it has been noted that the preferences of future generations with regard to

consumption versus environmental amenities may not be the same as those today, making the current market rate on consumption an inappropriate metric by which to discount future climate-related damages. Others argue that the discount rate should be below market rates to correct for market distortions and uncertainties or inefficiencies in intergenerational transfers of wealth, which in the Kaldor-Hicks logic are presumed to compensate future generations for damage (a potentially controversial assumption, as noted above) (Arrow et al. 1996, Weitzman 1999).

Further, a legitimate concern about both descriptive and prescriptive approaches is that they tend to obscure important heterogeneity in the population. The utility function that underlies the prescriptive approach assumes a representative agent with perfect foresight and no credit constraints. This is an artificial rendering of the real world that misses many of the frictions that characterize individuals' lives and indeed the available descriptive evidence supports this. For instance, many individuals smooth consumption by borrowing with credit cards that have relatively high rates. Some are unable to access traditional credit markets and rely on payday lending operations or other high-cost forms of smoothing consumption. Whether one puts greater weight on the prescriptive or descriptive approach, the high interest rates that credit-constrained individuals accept suggest that some account should be given to the discount rates revealed by their behavior.

We draw on both approaches but rely primarily on the descriptive approach to inform the choice of discount rate. With recognition of its limitations, we find this approach to be the most defensible and transparent given its consistency with the standard contemporary theoretical foundations of benefit-cost analysis and with the approach required by OMB's existing guidance. The logic of this framework also suggests that market rates should be used for discounting future consumption-equivalent damages. Regardless of the theoretical approach used to derive the appropriate discount rate(s), we note the inherent conceptual and practical difficulties of adequately capturing consumption trade-offs over many decades or even centuries. While relying primarily on the descriptive approach in selecting specific discount rates, the interagency group has been keenly aware of the deeply normative dimensions of both the debate over discounting in the intergenerational context and the consequences of selecting one discount rate over another.

Historically Observed Interest Rates

In a market with no distortions, the return to savings would equal the private return on investment, and the market rate of interest would be the appropriate choice for the social discount rate. In the real world risk, taxes, and other market imperfections drive a wedge between the risk-free rate of return on capital and the consumption rate of interest. Thus, the literature recognizes two conceptual discount concepts—the consumption rate of interest and the opportunity cost of capital.

According to OMB's Circular A-4, it is appropriate to use the rate of return on capital when a regulation is expected to displace or alter the use of capital in the private sector. In this case, OMB recommends Agencies use a discount rate of 7 percent. When regulation is expected to primarily affect private consumption—for instance, via higher prices for goods and services—

a lower discount rate of 3 percent is appropriate to reflect how private individuals trade-off current and future consumption.

The interagency group examined the economics literature and concluded that the consumption rate of interest is the correct concept to use in evaluating the benefits and costs of a marginal change in carbon emissions (see Lind 1990, Arrow et al 1996, and Arrow 2000). The consumption rate of interest also is appropriate when the impacts of a regulation are measured in consumption (-equivalent) units, as is done in the three integrated assessment models used for estimating the SCC.

Individuals use a variety of savings instruments that vary with risk level, time horizon, and tax characteristics. The standard analytic framework used to develop intuition about the discount rate typically assumes a representative agent with perfect foresight and no credit constraints. The risk-free rate is appropriate for discounting certain future benefits or costs, but the benefits calculated by IAMs are uncertain. To use the risk-free rate to discount uncertain benefits, these benefits first must be transformed into "certainty equivalents," that is the maximum certain amount that we would exchange for the uncertain amount. However, the calculation of the certainty-equivalent requires first estimating the correlation between the benefits of the policy and baseline consumption.

If the IAM projections of future impacts represent expected values (not certainty-equivalent values), then the appropriate discount rate generally does not equal the risk-free rate. If the benefits of the policy tend to be high in those states of the world in which consumption is low, then the certainty-equivalent benefits will be higher than the expected benefits (and vice versa). Since many (though not necessarily all) of the important impacts of climate change will flow through market sectors such as agriculture and energy, and since willingness to pay for environmental protections typically increases with income, we might expect a positive (though not necessarily perfect) correlation between the net benefits from climate policies and market returns. This line of reasoning suggests that the proper discount rate would exceed the riskless rate. Alternatively, a negative correlation between the returns to climate policies and market returns would imply that a discount rate below the riskless rate is appropriate.

This discussion suggests that both the post-tax riskless and risky rates can be used to capture individuals' consumption-equivalent interest rate. As a measure of the post-tax riskless rate, we calculate the average real return from Treasury notes over the longest time period available (those from Newell and Pizer 2003) and adjust for Federal taxes (the average marginal rate from tax years 2003 through 2006 is around 27 percent).^f This calculation produces a real interest rate of about 2.7 percent, which is roughly consistent with Circular A-4's recommendation to use 3 percent to represent the consumption rate of interest.^g A measure of the post-tax risky rate for investments whose returns are positively correlated with overall equity

^f The literature argues for a risk-free rate on government bonds as an appropriate measure of the consumption rate of interest. Arrow (2000) suggests that it is roughly 3-4 percent. OMB cites evidence of a 3.1 percent pre-tax rate for 10-year Treasury notes in the A-4 guidance. Newell and Pizer (2003) find real interest rates between 3.5 and 4 percent for 30-year Treasury securities.

^g The positive approach reflects how individuals make allocation choices across time, but it is important to keep in mind that we wish to reflect preferences for society as a whole, which generally has a longer planning horizon.

market returns can be obtained by adjusting pre-tax rates of household returns to risky investments (approximately 7 percent) for taxes, which yields a real rate of roughly 5 percent.^t

The Ramsey Equation

Ramsey discounting also provides a useful framework to inform the choice of a discount rate. Under this approach, the analyst applies either positive or normative judgments in selecting values for the key parameters of the Ramsey equation: η (coefficient of relative risk aversion or elasticity of the marginal utility of consumption) and ρ (pure rate of time preference).^u These are then combined with g (growth rate of per-capita consumption) to equal the interest rate at which future monetized damages are discounted: $\rho + \eta \cdot g$.^v In the simplest version of the Ramsey model, with an optimizing representative agent with perfect foresight, what we are calling the “Ramsey discount rate,” $\rho + \eta \cdot g$, will be equal to the rate of return to capital, i.e., the market interest rate.

A review of the literature provides some guidance on reasonable parameter values for the Ramsey discounting equation, based on both prescriptive and descriptive approaches.

- η . Most papers in the climate change literature adopt values for η in the range of 0.5 to 3 (Weitzman cites plausible values as those ranging from 1 to 4), although not all authors articulate whether their choice is based on prescriptive or descriptive reasoning.^w Dasgupta (2008) argues that η should be greater than 1 and may be as high as 3, since η equal to 1 suggests savings rates that do not conform to observed behavior.

^t Cambell et al (2001) estimates that the annual real return from stocks for 1900-1995 was about 7 percent. The annual real rate of return for the S&P 500 from 1950 – 2008 was about 6.8 percent. In the absence of a better way to population-weight the tax rates, we use the middle of the 20 – 40 percent range to derive a post-tax interest rate (Kotlikoff and Rapson 2006).

^u The parameter ρ measures the *pure rate of time preference*: people’s behavior reveals a preference for an increase in utility today versus the future. Consequently, it is standard to place a lower weight on utility in the future. The parameter η captures *diminishing marginal utility*: consumption in the future is likely to be higher than consumption today, so diminishing marginal utility of consumption implies that the same monetary damage will cause a smaller reduction of utility for wealthier individuals, either in the future or in current generations. If $\eta = 0$, then a one dollar increase in income is equally valuable regardless of level of income; if $\eta = 1$, then a one percent increase in income is equally valuable no matter the level of income; and if $\eta > 1$, then a one percent increase in income is less valuable to wealthier individuals.

^v In this case, g could be taken from the selected EMF socioeconomic scenarios or alternative assumptions about the rate of consumption growth.

^w Empirical estimates of η span a wide range of values. A benchmark value of 2 is near the middle of the range of values estimated or used by Szpiro (1986), Hall and Jones (2007), Arrow (2007), Dasgupta (2006, 2008), Weitzman (2007, 2009), and Nordhaus (2008). However, Chetty (2006) developed a method of estimating η using data on labor supply behavior. He shows that existing evidence of the effects of wage changes on labor supply imposes a tight upper bound on the curvature of utility over wealth ($CRRA < 2$) with the mean implied value of 0.71 and concludes that the standard expected utility model cannot generate high levels of risk aversion without contradicting established facts about labor supply. Recent work has jointly estimated the components of the Ramsey equation. Evans and Sezer (2005) estimate $\eta = 1.49$ for 22 OECD countries. They also estimate $\rho = 1.08$ percent per year using data on mortality rates. Anthoff, et al. (2009b) estimate $\eta = 1.18$, and $\rho = 1.4$ percent. When they multiply the bivariate probability distributions from their work and Evans and Sezer (2005) together, they find $\eta = 1.47$, and $\rho = 1.07$.

- p. With respect to the pure rate of time preference, most papers in the climate change literature adopt values for ρ in the range of 0 to 3 percent per year. The very low rates tend to follow from moral judgments involving intergenerational neutrality. Some have argued that to use any value other than $\rho = 0$ would unjustly discriminate against future generations (e.g., Arrow et al. 1996, Stern et al. 2006). However, even in an intergenerational setting, it may make sense to use a small positive pure rate of time preference because of the small probability of unforeseen cataclysmic events (Stern et al. 2006).
- g. A commonly accepted approximation is around 2 percent per year. For the socioeconomic scenarios used for this exercise, the EMF models assume that g is about 1.5-2 percent to 2100.

Some economists and non-economists have argued for constant discount rates below 2 percent based on the prescriptive approach. When grounded in the Ramsey framework, proponents of this approach have argued that a ρ of zero avoids giving preferential treatment to one generation over another. The choice of η has also been posed as an ethical choice linked to the value of an additional dollar in poorer countries compared to wealthier ones. Stern et al. (2006) applies this perspective through his choice of $\rho = 0.1$ percent per year, $\eta = 1$ and $g = 1.3$ percent per year, which yields an annual discount rate of 1.4 percent. In the context of permanent income savings behavior, however, Stern's assumptions suggest that individuals would save 93 percent of their income.^x

Recently, Stern (2008) revisited the values used in Stern et al. (2006), stating that there is a case to be made for raising η due to the amount of weight lower values place on damages far in the future (over 90 percent of expected damages occur after 2200 with $\eta = 1$). Using Stern's assumption that $\rho = 0.1$ percent, combined with a η of 1.5 to 2 and his original growth rate, yields a discount rate of greater than 2 percent.

We conclude that arguments made under the prescriptive approach can be used to justify discount rates between roughly 1.4 and 3.1 percent. In light of concerns about the most appropriate value for η , we find it difficult to justify rates at the lower end of this range under the Ramsey framework.

Accounting for Uncertainty in the Discount Rate

While the consumption rate of interest is an important driver of the benefits estimate, it is uncertain over time. Ideally, we would formally model this uncertainty, just as we do for climate sensitivity. Weitzman (1998, 2001) showed theoretically and Newell and Pizer (2003) and Groom et al. (2006) confirm empirically that discount rate uncertainty can have a large effect on net present values. A main result from these studies is that if there is a persistent element to the uncertainty in the discount rate (e.g., the rate follows a random walk), then it will result in an effective (or certainty-equivalent) discount rate that declines over time. Consequently, lower

^x Stern (2008) argues that building in a positive rate of exogenous technical change over time reduces the implied savings rate and that η at or above 2 are inconsistent with observed behavior with regard to equity. (At the same time, adding exogenous technical change—all else equal—would increase g as well.)

discount rates tend to dominate over the very long term (see Weitzman 1998, 1999, 2001; Newell and Pizer 2003; Groom et al. 2006; Gollier 2008; Summers and Zeckhauser 2008; and Gollier and Weitzman 2009).

The proper way to model discount rate uncertainty remains an active area of research. Newell and Pizer (2003) employ a model of how long-term interest rates change over time to forecast future discount rates. Their model incorporates some of the basic features of how interest rates move over time, and its parameters are estimated based on historical observations of long-term rates. Subsequent work on this topic, most notably Groom et al. (2006), uses more general models of interest rate dynamics to allow for better forecasts. Specifically, the volatility of interest rates depends on whether rates are currently low or high and the variation in the level of persistence over time.

While Newell and Pizer (2003) and Groom et al (2006) attempt formally to model uncertainty in the discount rate, others argue for a declining scale of discount rates applied over time (e.g., Weitzman 2001, and the UK's "Green Book" for regulatory analysis). This approach uses a higher discount rate initially, but applies a graduated scale of lower discount rates further out in time.^y A key question that has emerged with regard to both of these approaches is the trade-off between potential time inconsistency and giving greater weight to far future outcomes (see the EPA Science Advisory Board's recent comments on this topic as part of its review of their *Guidelines for Economic Analysis*).^z

The Discount Rates Selected for Estimating SCC

In light of disagreement in the literature on the appropriate market interest rate to use in this context and uncertainty about how interest rates may change over time, we use three discount rates to span a plausible range of certainty-equivalent constant discount rates: 2.5, 3, and 5 percent per year. Based on the review in the previous sections, the interagency workgroup determined that these three rates reflect reasonable judgments under both descriptive and prescriptive approaches.

The central value, 3 percent, is consistent with estimates provided in the economics literature and OMB's Circular A-4 guidance for the consumption rate of interest. As previously mentioned, the consumption rate of interest is the correct discounting concept to use when future damages from elevated temperatures are estimated in consumption-equivalent units. Further, 3 percent roughly corresponds to the after-tax riskless interest rate. The upper value of 5 percent is

^y For instance, the UK applies a discount rate of 3.5 percent to the first 30 years; 3 percent for years 31 - 75; 2.5 percent for years 76 - 125; 2 percent for years 126 - 200; 1.5 percent for years 201 - 300; and 1 percent after 300 years. As a sensitivity, it recommends a discount rate of 3 percent for the first 30 years, also decreasing over time.

^z Uncertainty in future damages is distinct from uncertainty in the discount rate. Weitzman (2008) argues that Stern's choice of a low discount rate was "right for the wrong reasons." He demonstrates how the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. Newbold and Daigneault, (2009) and Nordhaus (2009) find that Weitzman's result is sensitive to the functional forms chosen for climate sensitivity, utility, and consumption. Summers and Zeckhauser (2008) argue that uncertainty in future damages can also work in the other direction by increasing the benefits of waiting to learn the appropriate level of mitigation required.

included to represent the possibility that climate damages are positively correlated with market returns. Additionally, this discount rate may be justified by the high interest rates that many consumers use to smooth consumption across periods.

The low value, 2.5 percent, is included to incorporate the concern that interest rates are highly uncertain over time. It represents the average certainty-equivalent rate using the mean-reverting and random walk approaches from Newell and Pizer (2003) starting at a discount rate of 3 percent. Using this approach, the certainty equivalent is about 2.2 percent using the random walk model and 2.8 percent using the mean reverting approach.^{aa} Without giving preference to a particular model, the average of the two rates is 2.5 percent. Further, a rate below the riskless rate would be justified if climate investments are negatively correlated with the overall market rate of return. Use of this lower value also responds to certain judgments using the prescriptive or normative approach and to ethical objections that have been raised about rates of 3 percent or higher.

15A.5 REVISED SCC ESTIMATES

Our general approach to estimating SCC values is to run the three integrated assessment models (FUND, DICE, and PAGE) using the following inputs agreed upon by the interagency group:

- A Roe and Baker distribution for the climate sensitivity parameter bounded between 0 and 10 with a median of 3 °C and a cumulative probability between 2 and 4.5 °C of two-thirds.
- Five sets of GDP, population, and carbon emissions trajectories based on EMF-22.
- Constant annual discount rates of 2.5, 3, and 5 percent.

Because the climate sensitivity parameter is modeled probabilistically, and because PAGE and FUND incorporate uncertainty in other model parameters, the final output from each model run is a distribution over the SCC in year t .

For each of the IAMs, the basic computational steps for calculating the SCC in a particular year t are:

1. Input the path of emissions, GDP, and population from the selected EMF-22 scenarios, and the extrapolations based on these scenarios for post-2100 years.
2. Calculate the temperature effects and (consumption-equivalent) damages in each year resulting from the baseline path of emissions.
 - a. In PAGE, the consumption-equivalent damages in each period are calculated as a fraction of the EMF GDP forecast, depending on the temperature in that period relative to the pre-industrial average temperature in each region.
 - b. In FUND, damages in each period depend on both the level and the rate of temperature change in that period.

^{aa} Calculations done by Pizer et al. using the original simulation program from Newell and Pizer (2003).

- c. In DICE, temperature affects both consumption and investment, so we first adjust the EMF GDP paths as follows: Using the Cobb-Douglas production function with the DICE2007 parameters, we extract the path of exogenous technical change implied by the EMF GDP and population paths, then we recalculate the baseline GDP path taking into account climate damages resulting from the baseline emissions path.
3. Add an additional unit of carbon emissions in year t . (The exact unit varies by model.)
4. Recalculate the temperature effects and damages expected in all years beyond t resulting from this adjusted path of emissions, as in step 2.
5. Subtract the damages computed in step 2 from those in step 4 in each year. (DICE is run in 10-year time steps, FUND in annual time steps, while the time steps in PAGE vary.)
6. Discount the resulting path of marginal damages back to the year of emissions using the agreed upon fixed discount rates.
7. Calculate the SCC as the net present value of the discounted path of damages computed in step 6, divided by the unit of carbon emissions used to shock the models in step 3.
8. Multiply by 12/44 to convert from dollars per ton of carbon to dollars per ton of CO₂ (2007 dollars) in DICE and FUND. (All calculations are done in tons of CO₂ in PAGE).

The steps above were repeated in each model for multiple future years to cover the time horizons anticipated for upcoming rulemaking analysis. To maintain consistency across the three IAMs, climate damages are calculated as lost consumption in each future year.

It is important to note that each of the three models has a different default end year. The default time horizon is 2200 for PAGE, 2595 for DICE, and 3000 for the latest version of FUND. This is an issue for the multi-model approach because differences in SCC estimates may arise simply due to the model time horizon. Many consider 2200 too short a time horizon because it could miss a significant fraction of damages under certain assumptions about the growth of marginal damages and discounting, so each model is run here through 2300. This step required a small adjustment in the PAGE model only. This step also required assumptions about GDP, population, and greenhouse gas emission trajectories after 2100, the last year for which these data are available from the EMF-22 models. (A more detailed discussion of these assumptions is included in the Annex.)

This exercise produces 45 separate distributions of the SCC for a given year, the product of 3 models, 3 discount rates, and 5 socioeconomic scenarios. This is clearly too many separate distributions for consideration in a regulatory impact analysis.

To produce a range of plausible estimates that still reflects the uncertainty in the estimation exercise, the distributions from each of the models and scenarios are equally weighed and combined to produce three separate probability distributions for SCC in a given year, one for each assumed discount rate. These distributions are then used to define a range of point estimates for the global SCC. In this way, no IAM or socioeconomic scenario is given greater weight than another. Because the literature shows that the SCC is quite sensitive to assumptions about the discount rate, and because no consensus exists on the appropriate rate to use in an intergenerational context, we present SCCs based on the average values across models and socioeconomic scenarios for each discount rate.

The interagency group selected four SCC values for use in regulatory analyses. Three values are based on the average SCC across models and socioeconomic and emissions scenarios at the 2.5, 3, and 5 percent discount rates. The fourth value is included to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. (The full set of distributions by model and scenario combination is included in the Annex.) As noted above, the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range.

As previously discussed, low probability, high impact events are incorporated into the SCC values through explicit consideration of their effects in two of the three models as well as the use of a probability density function for equilibrium climate sensitivity. Treating climate sensitivity probabilistically results in more high-temperature outcomes, which in turn lead to higher projections of damages. Although FUND does not include catastrophic damages (in contrast to the other two models), its probabilistic treatment of the equilibrium climate sensitivity parameter will directly affect the non-catastrophic damages that are a function of the rate of temperature change.

In Table 15A.5.1, we begin by presenting SCC estimates for 2010 by model, scenario, and discount rate to illustrate the variability in the SCC across each of these input parameters. As expected, higher discount rates consistently result in lower SCC values, while lower discount rates result in higher SCC values for each socioeconomic trajectory. It is also evident that there are differences in the SCC estimated across the three main models. For these estimates, FUND produces the lowest estimates, while PAGE generally produces the highest estimates.

Table 15A.5.1 Disaggregated Social Cost of CO₂ Values by Model, Socioeconomic Trajectory, and Discount Rate for 2010 (in 2007 dollars)

<i>Discount rate:</i>		5%	3%	2.5%	3%
<i>Model</i>	<i>Scenario</i>	Avg	Avg	Avg	95th
DICE	IMAGE	10.8	35.8	54.2	70.8
	MERGE	7.5	22.0	31.6	42.1
	Message	9.8	29.8	43.5	58.6
	MiniCAM	8.6	28.8	44.4	57.9
	550 Average	8.2	24.9	37.4	50.8
PAGE	IMAGE	8.3	39.5	65.5	142.4
	MERGE	5.2	22.3	34.6	82.4
	Message	7.2	30.3	49.2	115.6
	MiniCAM	6.4	31.8	54.7	115.4
	550 Average	5.5	25.4	42.9	104.7
FUND	IMAGE	-1.3	8.2	19.3	39.7
	MERGE	-0.3	8.0	14.8	41.3
	Message	-1.9	3.6	8.8	32.1
	MiniCAM	-0.6	10.2	22.2	42.6
	550 Average	-2.7	-0.2	3.0	19.4

These results are not surprising when compared to the estimates in the literature for the latest versions of each model. For example, adjusting the values from the literature that were used to develop interim SCC values to 2007 dollars for the year 2010 (assuming, as we did for the interim process, that SCC grows at 3 percent per year), FUND yields SCC estimates at or near zero for a 5 percent discount rate and around \$9 per ton for a 3 percent discount rate. There are far fewer estimates using the latest versions of DICE and PAGE in the literature: Using similar adjustments to generate 2010 estimates, we calculate a SCC from DICE (based on Nordhaus 2008) of around \$9 per ton for a 5 percent discount rate, and a SCC from PAGE (based on Hope 2006, 2008) close to \$8 per ton for a 4 percent discount rate. Note that these comparisons are only approximate since the literature generally relies on Ramsey discounting, while we have assumed constant discount rates.^{bb}

^{bb} Nordhaus (2008) runs DICE2007 with $\rho = 1.5$ and $\eta = 2$. The default approach in PAGE2002 (version 1.4epm) treats ρ and η as random parameters, specified using a triangular distribution such that the min, mode, and max = 0.1, 1, and 2 for ρ , and 0.5, 1, and 2 for η , respectively. The FUND default value for η is 1, and Tol generates SCC estimates for values of $\rho = 0, 1$, and 3 in many recent papers (e.g. Anthoff et al. 2009). The path of per-capita consumption growth, g , varies over time but is treated deterministically in two of the three models. In DICE, g is endogenous. Under Ramsey discounting, as economic growth slows in the future, the large damages from climate change that occur far out in the future are discounted at a lower rate than impacts that occur in the nearer term.

The SCC estimates from FUND are sensitive to differences in emissions paths but relatively insensitive to differences in GDP paths across scenarios, while the reverse is true for DICE and PAGE. This likely occurs because of several structural differences among the models. Specifically in DICE and PAGE, the fraction of economic output lost due to climate damages increases with the level of temperature alone, whereas in FUND the fractional loss also increases with the rate of temperature change. Furthermore, in FUND increases in income over time decrease vulnerability to climate change (a form of adaptation), whereas this does not occur in DICE and PAGE. These structural differences among the models make FUND more sensitive to the path of emissions and less sensitive to GDP compared to DICE and PAGE.

Figure 15A.5.1 shows that IMAGE has the highest GDP in 2100 while MERGE Optimistic has the lowest. The ordering of global GDP levels in 2100 directly corresponds to the rank ordering of SCC for PAGE and DICE. For FUND, the correspondence is less clear, a result that is to be expected given its less direct relationship between its damage function and GDP.

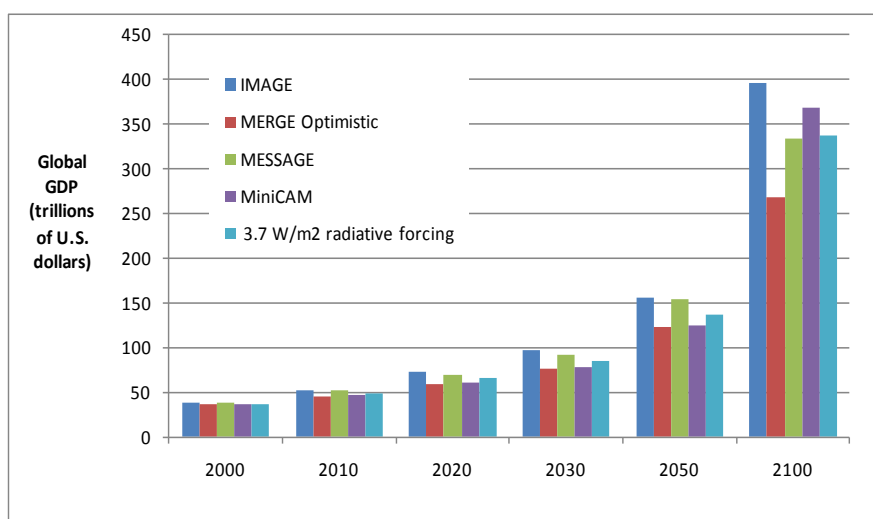


Figure 15A.5.1 Level of Global GDP across EMF Scenarios

Table 15A.5.2 shows the four selected SCC values in five-year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using a simple linear interpolation.

Table 15A.5.2 Social Cost of CO₂, 2010 – 2050 (in 2007 dollars)

Discount	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

The SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. Note that this approach allows us to estimate the growth rate of the SCC directly using DICE, PAGE, and FUND rather than assuming a constant annual growth rate as was done for the interim estimates (using 3 percent). This helps to ensure that the estimates are internally consistent with other modeling assumptions. Table 15A.5.3 illustrates how the growth rate for these four SCC estimates varies over time. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 15A.5.3 Changes in the Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Growth Rate (%)	5%	3%	2.5%	3.0%
	Avg	Avg	Avg	95th
2010-2020	3.6%	2.1%	1.7%	2.2%
2020-2030	3.7%	2.2%	1.8%	2.2%
2030-2040	2.7%	1.8%	1.6%	1.8%
2040-2050	2.1%	1.4%	1.1%	1.3%

While the SCC estimate grows over time, the future monetized value of emissions reductions in each year (the SCC in year t multiplied by the change in emissions in year t) must be discounted to the present to determine its total net present value for use in regulatory analysis. Damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency—i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate. For example, climate damages in the year 2020 that are calculated using a SCC based on a 5 percent discount rate also should be discounted back to the analysis year using a 5 percent discount rate.^{cc}

^{cc} However, it is possible that other benefits or costs of proposed regulations unrelated to CO₂ emissions will be discounted at rates that differ from those used to develop the SCC estimates.

15A.6 LIMITATIONS OF THE ANALYSIS

As noted, any estimate of the SCC must be taken as provisional and subject to further refinement (and possibly significant change) in accordance with evolving scientific, economic, and ethical understandings. During the course of our modeling, it became apparent that there are several areas in particular need of additional exploration and research. These caveats, and additional observations in the following section, are necessary to consider when interpreting and applying the SCC estimates.

Incomplete treatment of non-catastrophic damages. The impacts of climate change are expected to be widespread, diverse, and heterogeneous. In addition, the exact magnitude of these impacts is uncertain because of the inherent complexity of climate processes, the economic behavior of current and future populations, and our inability to accurately forecast technological change and adaptation. Current IAMs do not assign value to all of the important physical, ecological, and economic impacts of climate change recognized in the climate change literature (some of which are discussed above) because of lack of precise information on the nature of damages and because the science incorporated into these models understandably lags behind the most recent research. Our ability to quantify and monetize impacts will undoubtedly improve with time. But it is also likely that even in future applications, a number of potentially significant damage categories will remain non-monetized. (Ocean acidification is one example of a potentially large damage from CO₂ emissions not quantified by any of the three models. Species and wildlife loss is another example that is exceedingly difficult to monetize.)

Incomplete treatment of potential catastrophic damages. There has been considerable recent discussion of the risk of catastrophic impacts and how best to account for extreme scenarios, such as the collapse of the Atlantic Meridional Overturning Circulation or the West Antarctic Ice Sheet, or large releases of methane from melting permafrost and warming oceans. Weitzman (2009) suggests that catastrophic damages are extremely large—so large, in fact, that the damages from a low probability, catastrophic event far in the future dominate the effect of the discount rate in a present value calculation and result in an infinite willingness-to-pay for mitigation today. However, Nordhaus (2009) concluded that the conditions under which Weitzman's results hold “are limited and do not apply to a wide range of potential uncertain scenarios.”

Using a simplified IAM, Newbold and Daigneault (2009) confirmed the potential for large catastrophe risk premiums but also showed that the aggregate benefit estimates can be highly sensitive to the shapes of both the climate sensitivity distribution and the damage function at high temperature changes. Pindyck (2009) also used a simplified IAM to examine high-impact, low-probability risks, using a right-skewed gamma distribution for climate sensitivity as well as an uncertain damage coefficient, but in most cases found only a modest risk premium. Given this difference in opinion, further research in this area is needed before its practical significance can be fully understood and a reasonable approach developed to account for such risks in regulatory analysis. (The next section discusses the scientific evidence on catastrophic impacts in greater detail.)

Uncertainty in extrapolation of damages to high temperatures: The damage functions in these IAMs are typically calibrated by estimating damages at moderate temperature increases (e.g., DICE was calibrated at 2.5 °C) and extrapolated to far higher temperatures by assuming

that damages increase as some power of the temperature change. Hence, estimated damages are far more uncertain under more extreme climate change scenarios.

Incomplete treatment of adaptation and technological change: Each of the three integrated assessment models used here assumes a certain degree of low- or no-cost adaptation. For instance, Tol assumes a great deal of adaptation in FUND, including widespread reliance on air conditioning; so much so, that the largest single benefit category in FUND is the reduced electricity costs from not having to run air conditioning as intensively (NRC 2009).

Climate change also will increase returns on investment to develop technologies that allow individuals to cope with adverse climate conditions, and IAMs to do not adequately account for this directed technological change.^{dd} For example, scientists may develop crops that are better able to withstand higher and more variable temperatures. Although DICE and FUND have both calibrated their agricultural sectors under the assumption that farmers will change land use practices in response to climate change (Mastrandrea, 2009), they do not take into account technological changes that lower the cost of this adaptation over time. On the other hand, the calibrations do not account for increases in climate variability, pests, or diseases, which could make adaptation more difficult than assumed by the IAMs for a given temperature change. Hence, models do not adequately account for potential adaptation or technical change that might alter the emissions pathway and resulting damages. In this respect, it is difficult to determine whether the incomplete treatment of adaptation and technological change in these IAMs understate or overstate the likely damages.

Risk aversion: A key question unanswered during this interagency process is what to assume about relative risk aversion with regard to high-impact outcomes. These calculations do not take into account the possibility that individuals may have a higher willingness to pay to reduce the likelihood of low-probability, high-impact damages than they do to reduce the likelihood of higher-probability, but lower-impact, damages with the same expected cost. (The inclusion of the 95th percentile estimate in the final set of SCC values was largely motivated by this concern.) If individuals do show such a higher willingness to pay, a further question is whether that fact should be taken into account for regulatory policy. Even if individuals are not risk-averse for such scenarios, it is possible that regulatory policy should include a degree of risk-aversion.

Assuming a risk-neutral representative agent is consistent with OMB's Circular A-4, which advises that the estimates of benefits and costs used in regulatory analysis are usually based on the average or the expected value and that "emphasis on these expected values is appropriate as long as society is 'risk neutral' with respect to the regulatory alternatives. While this may not always be the case, [analysts] should in general assume 'risk neutrality' in [their] analysis."

Nordhaus (2008) points to the need to explore the relationship between risk and income in the context of climate change across models and to explore the role of uncertainty regarding various parameters in the results. Using FUND, Anthoff et al (2009) explored the sensitivity of

^{dd} However these research dollars will be diverted from whatever their next best use would have been in the absence of climate change (so productivity/GDP would have been still higher).

the SCC to Ramsey equation parameter assumptions based on observed behavior. They conclude that “the assumed rate of risk aversion is at least as important as the assumed rate of time preference in determining the social cost of carbon.” Since Circular A-4 allows for a different assumption on risk preference in regulatory analysis if it is adequately justified, we plan to continue investigating this issue.

15A.7 A FURTHER DISCUSSION OF CATASTROPHIC IMPACTS AND DAMAGE FUNCTIONS

As noted above, the damage functions underlying the three IAMs used to estimate the SCC may not capture the economic effects of all possible adverse consequences of climate change and may therefore lead to underestimates of the SCC (Mastrandrea 2009). In particular, the models’ functional forms may not adequately capture: (1) potentially discontinuous “tipping point” behavior in Earth systems, (2) inter-sectoral and inter-regional interactions, including global security impacts of high-end warming, and (3) limited near-term substitutability between damage to natural systems and increased consumption.

It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling. In the meantime, we discuss some of the available evidence.

Extrapolation of climate damages to high levels of warming

The damage functions in the models are calibrated at moderate levels of warming and should therefore be viewed cautiously when extrapolated to the high temperatures found in the upper end of the distribution. Recent science suggests that there are a number of potential climatic “tipping points” at which the Earth system may exhibit discontinuous behavior with potentially severe social and economic consequences (e.g., Lenton et al, 2008, Kriegler et al., 2009). These tipping points include the disruption of the Indian Summer Monsoon, dieback of the Amazon Rainforest and boreal forests, collapse of the Greenland Ice Sheet and the West Antarctic Ice Sheet, reorganization of the Atlantic Meridional Overturning Circulation, strengthening of El Niño-Southern Oscillation, and the release of methane from melting permafrost. Many of these tipping points are estimated to have thresholds between about 3 °C and 5 °C (Lenton et al., 2008). Probabilities of several of these tipping points were assessed through expert elicitation in 2005–2006 by Kriegler et al. (2009); results from this study are highlighted in Table 15A.7.1. Ranges of probability are averaged across core experts on each topic.

As previously mentioned, FUND does not include potentially catastrophic effects. DICE assumes a small probability of catastrophic damages that increases with increased warming, but the damages from these risks are incorporated as expected values (i.e., ignoring potential risk aversion). PAGE models catastrophic impacts in a probabilistic framework (see Figure 15A.4.1), so the high-end output from PAGE potentially offers the best insight into the SCC if the world were to experience catastrophic climate change. For instance, at the 95th percentile and a 3 percent discount rate, the SCC estimated by PAGE across the five socioeconomic and emission trajectories of \$113 per ton of CO₂ is almost double the value estimated by DICE, \$58 per ton in

2010. We cannot evaluate how well the three models account for catastrophic or non-catastrophic impacts, but this estimate highlights the sensitivity of SCC values in the tails of the distribution to the assumptions made about catastrophic impacts.

Table 15A.7.1 Probabilities of Various Tipping Points from Expert Elicitation

Possible Tipping Points	Duration before effect is fully realized (in years)	Additional Warming by 2100		
		0.5-1.5 C	1.5-3.0 C	3-5 C
Reorganization of Atlantic Meridional Overturning Circulation	about 100	0-18%	6-39%	18-67%
Greenland Ice Sheet collapse	at least 300	8-39%	33-73%	67-96%
West Antarctic Ice Sheet collapse	at least 300	5-41%	10-63%	33-88%
Dieback of Amazon rainforest	about 50	2-46%	14-84%	41-94%
Strengthening of El Niño-Southern Oscillation	about 100	1-13%	6-32%	19-49%
Dieback of boreal forests	about 50	13-43%	20-81%	34-91%
Shift in Indian Summer Monsoon	about 1	Not formally assessed		
Release of methane from melting permafrost	Less than 100	Not formally assessed.		

PAGE treats the possibility of a catastrophic event probabilistically, while DICE treats it deterministically (that is, by adding the expected value of the damage from a catastrophe to the aggregate damage function). In part, this results in different probabilities being assigned to a catastrophic event across the two models. For instance, PAGE places a probability near zero on a catastrophe at 2.5 °C warming, while DICE assumes a 4 percent probability of a catastrophe at 2.5 °C. By comparison, Kriegler et al. (2009) estimate a probability of at least 16-36 percent of crossing at least one of their primary climatic tipping points in a scenario with temperatures about 2-4 °C warmer than pre-Industrial levels in 2100.

It is important to note that crossing a climatic tipping point will not necessarily lead to an economic catastrophe in the sense used in the IAMs. A tipping point is a critical threshold across which some aspect of the Earth system starts to shift into a qualitatively different state (for instance, one with dramatically reduced ice sheet volumes and higher sea levels). In the IAMs, a catastrophe is a low-probability environmental change with high economic impact.

Failure to incorporate inter-sectoral and inter-regional interactions

The damage functions do not fully incorporate either inter-sectoral or inter-regional interactions. For instance, while damages to the agricultural sector are incorporated, the effects of changes in food supply on human health are not fully captured and depend on the modeler's choice of studies used to calibrate the IAM. Likewise, the effects of climate damages in one region of the world on another region are not included in some of the models (FUND includes

the effects of migration from sea level rise). These inter-regional interactions, though difficult to quantify, are the basis for climate-induced national and economic security concerns (e.g., Campbell et al., 2007; U.S. Department of Defense 2010) and are particularly worrisome at higher levels of warming. High-end warming scenarios, for instance, project water scarcity affecting 4.3-6.9 billion people by 2050, food scarcity affecting about 120 million additional people by 2080, and the creation of millions of climate refugees (Easterling et al., 2007; Campbell et al., 2007).

Imperfect substitutability of environmental amenities

Data from the geological record of past climate changes suggests that 6 °C of warming may have severe consequences for natural systems. For instance, during the Paleocene-Eocene Thermal Maximum about 55.5 million years ago, when the Earth experienced a geologically rapid release of carbon associated with an approximately 5 °C increase in global mean temperatures, the effects included shifts of about 400-900 miles in the range of plants (Wing et al., 2005), and dwarfing of both land mammals (Gingerich, 2006) and soil fauna (Smith et al., 2009).

The three IAMs used here assume that it is possible to compensate for the economic consequences of damages to natural systems through increased consumption of non-climate goods, a common assumption in many economic models. In the context of climate change, however, it is possible that the damages to natural systems could become so great that no increase in consumption of non-climate goods would provide complete compensation (Levy et al., 2005). For instance, as water supplies become scarcer or ecosystems become more fragile and less bio-diverse, the services they provide may become increasingly more costly to replace. Uncalibrated attempts to incorporate the imperfect substitutability of such amenities into IAMs (Stern and Persson, 2008) indicate that the optimal degree of emissions abatement can be considerably greater than is commonly recognized.

15A.8 CONCLUSION

The interagency group selected four SCC estimates for use in regulatory analyses. For 2010, these estimates are \$5, \$21, \$35, and \$65 (in 2007 dollars). The first three estimates are based on the average SCC across models and socioeconomic and emissions scenarios at the 5, 3, and 2.5 percent discount rates, respectively. The fourth value is included to represent the higher-than-expected impacts from temperature change further out in the tails of the SCC distribution. For this purpose, we use the SCC value for the 95th percentile at a 3 percent discount rate. The central value is the average SCC across models at the 3 percent discount rate. For purposes of capturing the uncertainties involved in regulatory impact analysis, we emphasize the importance and value of considering the full range. These SCC estimates also grow over time. For instance, the central value increases to \$24 per ton of CO₂ in 2015 and \$26 per ton of CO₂ in 2020.

We noted a number of limitations to this analysis, including the incomplete way in which the integrated assessment models capture catastrophic and non-catastrophic impacts, their incomplete treatment of adaptation and technological change, uncertainty in the extrapolation of damages to high temperatures, and assumptions regarding risk aversion. The limited amount of research linking climate impacts to economic damages makes this modeling exercise even more

difficult. It is the hope of the interagency group that over time researchers and modelers will work to fill these gaps and that the SCC estimates used for regulatory analysis by the Federal government will continue to evolve with improvements in modeling.

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15A.9 ANNEX

Table 15A.9.1 Annual SCC Values: 2010–2050 (in 2007 dollars)

Discount Rate	5%	3%	2.5%	3%
Year	Avg	Avg	Avg	95th
2010	4.7	21.4	35.1	64.9
2011	4.9	21.9	35.7	66.5
2012	5.1	22.4	36.4	68.1
2013	5.3	22.8	37.0	69.6
2014	5.5	23.3	37.7	71.2
2015	5.7	23.8	38.4	72.8
2016	5.9	24.3	39.0	74.4
2017	6.1	24.8	39.7	76.0
2018	6.3	25.3	40.4	77.5
2019	6.5	25.8	41.0	79.1
2020	6.8	26.3	41.7	80.7
2021	7.1	27.0	42.5	82.6
2022	7.4	27.6	43.4	84.6
2023	7.7	28.3	44.2	86.5
2024	7.9	28.9	45.0	88.4
2025	8.2	29.6	45.9	90.4
2026	8.5	30.2	46.7	92.3
2027	8.8	30.9	47.5	94.2
2028	9.1	31.5	48.4	96.2
2029	9.4	32.1	49.2	98.1
2030	9.7	32.8	50.0	100.0
2031	10.0	33.4	50.9	102.0
2032	10.3	34.1	51.7	103.9
2033	10.6	34.7	52.5	105.8
2034	10.9	35.4	53.4	107.8
2035	11.2	36.0	54.2	109.7
2036	11.5	36.7	55.0	111.6
2037	11.8	37.3	55.9	113.6
2038	12.1	37.9	56.7	115.5
2039	12.4	38.6	57.5	117.4
2040	12.7	39.2	58.4	119.3
2041	13.0	39.8	59.0	121.0
2042	13.3	40.4	59.7	122.7
2043	13.6	40.9	60.4	124.4
2044	13.9	41.5	61.0	126.1
2045	14.2	42.1	61.7	127.8
2046	14.5	42.6	62.4	129.4
2047	14.8	43.2	63.0	131.1
2048	15.1	43.8	63.7	132.8
2049	15.4	44.4	64.4	134.5
2050	15.7	44.9	65.0	136.2

This Annex provides additional technical information about the non-CO₂ emission projections used in the modeling and the method for extrapolating emissions forecasts through 2300 and shows the full distribution of 2010 SCC estimates by model and scenario combination.

15A.9.1 Other (non-CO₂) gases

In addition to fossil and industrial CO₂ emissions, each EMF scenario provides projections of methane (CH₄), nitrous oxide (N₂O), fluorinated gases, and net land use CO₂ emissions to 2100. These assumptions are used in all three IAMs while retaining each model's default radiative forcings (RF) due to other factors (e.g., aerosols and other gases). Specifically, to obtain the RF associated with the non-CO₂ EMF emissions only, we calculated the RF associated with the EMF atmospheric CO₂ concentrations and subtracted them from the EMF total RF.^{ee} This approach respects the EMF scenarios as much as possible and at the same time takes account of those components not included in the EMF projections. Since each model treats non-CO₂ gases differently (e.g., DICE lumps all other gases into one composite exogenous input), this approach was applied slightly differently in each of the models.

FUND: Rather than relying on RF for these gases, the actual emissions from each scenario were used in FUND. The model default trajectories for CH₄, N₂O, SF₆, and the CO₂ emissions from land were replaced with the EMF values.

PAGE: PAGE models CO₂, CH₄, sulfur hexafluoride (SF₆), and aerosols and contains an "excess forcing" vector that includes the RF for everything else. To include the EMF values, we removed the default CH₄ and SF₆ factors^{ff}, decomposed the excess forcing vector, and constructed a new excess forcing vector that includes the EMF RF for CH₄, N₂O, and fluorinated gases, as well as the model default values for aerosols and other factors. Net land use CO₂ emissions were added to the fossil and industrial CO₂ emissions pathway.

DICE: DICE presents the greatest challenge because all forcing due to factors other than industrial CO₂ emissions is embedded in an exogenous non-CO₂ RF vector. To decompose this exogenous forcing path into EMF non-CO₂ gases and other gases, we relied on the references in DICE2007 to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report (AR4) and the discussion of aerosol forecasts in the IPCC's Third Assessment Report (TAR) and in AR4, as explained below. In DICE2007, Nordhaus assumes that exogenous forcing from all non-CO₂ sources is -0.06 W/m² in 2005, as reported in AR4, and increases linearly to 0.3 W/m² in 2105, based on GISS projections, and then stays constant after that time.

According to AR4, the RF in 2005 from CH₄, N₂O, and halocarbons (approximately similar to the F-gases in the EMF-22 scenarios) was $0.48 + 0.16 + 0.34 = 0.98$ W/m² and RF from total aerosols was -1.2 W/m². Thus, the -0.06 W/m² non-CO₂ forcing in DICE can be decomposed into: 0.98 W/m² due to the EMF non-CO₂ gases, -1.2 W/m² due to aerosols, and the remainder, 0.16 W/m², due to other residual forcing.

^{ee} Note EMF did not provide CO₂ concentrations for the IMAGE reference scenario. Thus, for this scenario, we fed the fossil, industrial, and land CO₂ emissions into MAGICC (considered a "neutral arbiter" model, which is tuned to emulate the major global climate models) and the resulting CO₂ concentrations were used. Note also that MERGE assumes a neutral biosphere so net land CO₂ emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

^{ff} Both the model default CH₄ emissions and the initial atmospheric CH₄ is set to zero to avoid double counting the effect of past CH₄ emissions.

For subsequent years, we calculated the DICE default RF from aerosols and other non-CO₂ gases based on the following two assumptions:

- (1) RF from aerosols declines linearly from 2005 to 2100 at the rate projected by the TAR and then stays constant thereafter; and
- (2) With respect to RF from non-CO₂ gases not included in the EMF-22 scenarios, the share of non-aerosol RF matches the share implicit in the AR4 summary statistics cited above and remains constant over time.

Assumption (1) means that the RF from aerosols in 2100 equals 66 percent of that in 2000, which is the fraction of the TAR projection of total RF from aerosols (including sulfates, black carbon, and organic carbon) in 2100 vs. 2000 under the A1B SRES emissions scenario. Since the SRES marker scenarios were not updated for the AR4, the TAR provides the most recent IPCC projection of aerosol forcing. We rely on the A1B projection from the TAR because it provides one of the lower aerosol forecasts among the SRES marker scenarios and is more consistent with the AR4 discussion of the post-SRES literature on aerosols:

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulfur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. {WGIII 3.2, TS.3, SPM}.^{gg}

Assuming a simple linear decline in aerosols from 2000 to 2100 also is more consistent with the recent literature on these emissions. For example, the figure below shows that the sulfur dioxide emissions peak over the short term of some SRES scenarios above the upper bound estimates of the more recent scenarios.^{hh} Recent scenarios project sulfur emissions to peak earlier and at lower levels compared to the SRES in part because of new information about present and planned sulfur legislation in some developing countries, such as India and China.ⁱⁱ The lower-bound projections of the recent literature have also shifted downward slightly compared to the SRES scenario (IPCC 2007).

With these assumptions, the DICE aerosol forcing changes from -1.2 in 2005 to -0.792 in 2105 W/m²; forcing due to other non-CO₂ gases not included in the EMF scenarios declines from 0.160 to 0.153 W/m².

^{gg} AR4 Synthesis Report, p. 44, http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

^{hh} See Smith, S.J., R. Andres, E. Conception, and J. Lurz, 2004: Historical sulfur dioxide emissions, 1850-2000: methods and results. Joint Global Research Institute, College Park, 14 pp.

ⁱⁱ See Carmichael, G., D. Streets, G. Calori, M. Amann, M. Jacobson, J. Hansen, and H. Ueda, 2002: Changing trends in sulphur emissions in Asia: implications for acid deposition, air pollution, and climate. *Environmental Science and Technology*, 36(22):4707- 4713; Streets, D., K. Jiang, X. Hu, J. Sinton, X.-Q. Zhang, D. Xu, M. Jacobson, and J. Hansen, 2001: Recent reductions in China's greenhouse gas emissions. *Science*, 294(5548): 1835-1837.

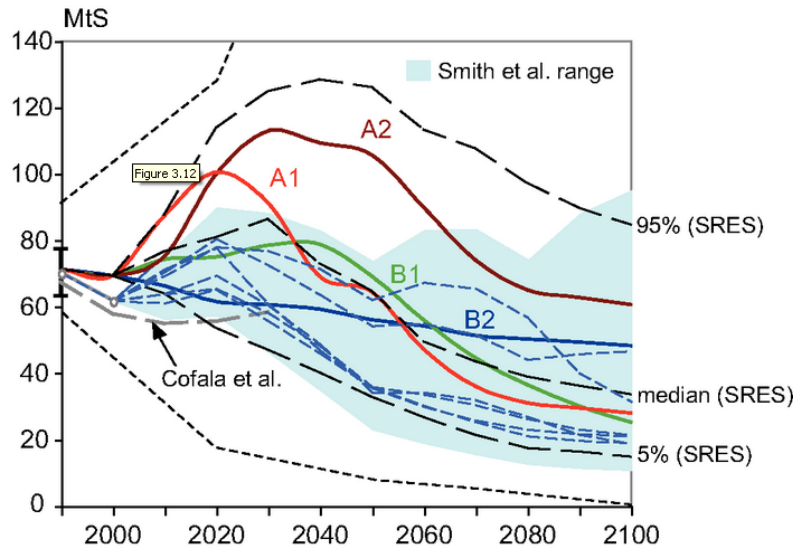


Figure 15A.9.1 Sulfur Dioxide Emission Scenarios

Notes: Thick colored lines depict the four SRES marker scenarios and black dashed lines show the median, 5th, and 95th percentile of the frequency distribution for the full ensemble of 40 SRES scenarios. The blue area (and the thin dashed lines in blue) illustrates individual scenarios and the range of Smith et al. (2004). Dotted lines indicate the minimum and maximum of SO₂ emissions scenarios developed pre-SRES.

Source: IPCC (2007), AR4 WGIII 3.2,

http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch3-ens3-2-2-4.html.

Although other approaches to decomposing the DICE exogenous forcing vector are possible, initial sensitivity analysis suggests that the differences among reasonable alternative approaches are likely to be minor. For example, adjusting the TAR aerosol projection above to assume that aerosols will be maintained at 2000 levels through 2100 reduces average SCC values (for 2010) by approximately 3 percent (or less than \$2); assuming all aerosols are phased out by 2100 increases average 2010 SCC values by 6-7 percent (or \$0.50-\$3)—depending on the discount rate. These differences increase slightly for SCC values in later years but are still well within 10 percent of each other as far out as 2050.

Finally, as in PAGE, the EMF net land use CO₂ emissions are added to the fossil and industrial CO₂ emissions pathway.

15A.9.2 Extrapolating Emissions Projections to 2300

To run each model through 2300 requires assumptions about GDP, population, greenhouse gas emissions, and radiative forcing trajectories after 2100, the last year for which these projections are available from the EMF-22 models. These inputs were extrapolated from 2100 to 2300 as follows:

1. Population growth rate declines linearly, reaching zero in the year 2200.
2. GDP/per capita growth rate declines linearly, reaching zero in the year 2300.

3. The decline in the fossil and industrial carbon intensity (CO_2/GDP) growth rate over 2090-2100 is maintained from 2100 through 2300.
4. Net land use CO_2 emissions decline linearly, reaching zero in the year 2200.
5. Non- CO_2 radiative forcing remains constant after 2100.

Long run stabilization of GDP per capita was viewed as a more realistic simplifying assumption than a linear or exponential extrapolation of the pre-2100 economic growth rate of each EMF scenario. This is based on the idea that increasing scarcity of natural resources and the degradation of environmental sinks available for assimilating pollution from economic production activities may eventually overtake the rate of technological progress. Thus, the overall rate of economic growth may slow over the very long run. The interagency group also considered allowing an exponential decline in the growth rate of GDP per capita. However, since this would require an additional assumption about how close to zero the growth rate would get by 2300, the group opted for the simpler and more transparent linear extrapolation to zero by 2300.

The population growth rate is also assumed to decline linearly, reaching zero by 2200. This assumption is reasonably consistent with the United Nations long run population forecast, which estimates global population to be fairly stable after 2150 in the medium scenario (UN 2004).^{jj} The resulting range of EMF population trajectories (figure below) also encompass the UN medium scenario forecasts through 2300—global population of 8.5 billion by 2200, and 9 billion by 2300.

Maintaining the decline in the 2090-2100 carbon intensity growth rate (i.e., CO_2 per dollar of GDP) through 2300 assumes that technological improvements and innovations in the areas of energy efficiency and other carbon reducing technologies (possibly including currently unavailable methods) will continue to proceed at roughly the same pace that is projected to occur towards the end of the forecast period for each EMF scenario. This assumption implies that total cumulative emissions in 2300 will be between 5,000 and 12,000 GtC, which is within the range of the total potential global carbon stock estimated in the literature.

Net land use CO_2 emissions are expected to stabilize in the long run, so in the absence of any post 2100 projections, the group assumed a linear decline to zero by 2200. Given no a priori reasons for assuming a long run increase or decline in non- CO_2 radiative forcing, it is assumed to remain at the 2100 levels for each EMF scenario through 2300.

Figures below show the paths of global population, GDP, fossil and industrial CO_2 emissions, net land CO_2 emissions, non- CO_2 radiative forcing, and CO_2 intensity (fossil and industrial CO_2 emissions/GDP) resulting from these assumptions.

^{jj} United Nations. 2004. *World Population to 2300*.
<http://www.un.org/esa/population/publications/longrange2/worldpop2300final.pdf>

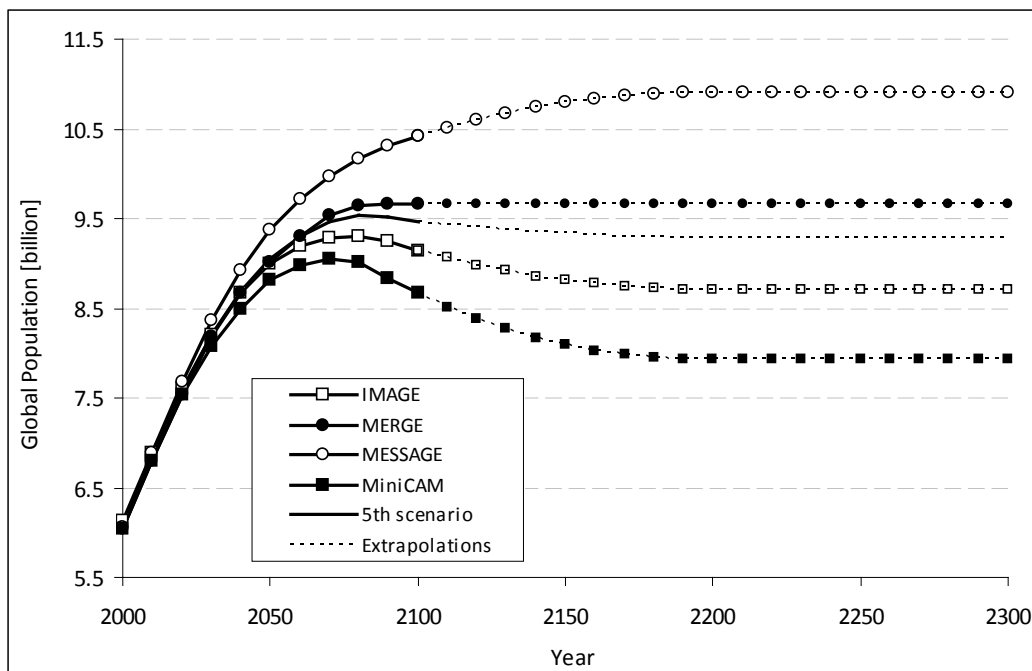


Figure 15A.9.2 Global Population, 2000-2300 (Post-2100 extrapolations assume the population growth rate changes linearly to reach a zero growth rate by 2200.)

Note: In the fifth scenario, 2000-2100 population is equal to the average of the population under the 550 ppm CO_{2e}, full-participation, not-to-exceed scenarios considered by each of the four models.

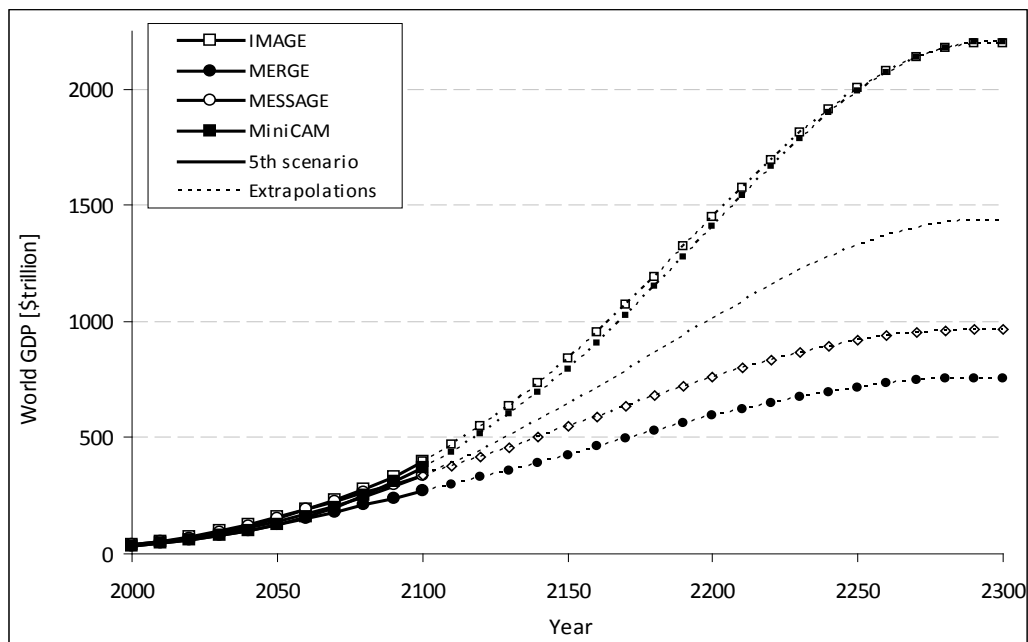


Figure 15A.9.3 World GDP, 2000-2300 (Post-2100 extrapolations assume GDP per capita growth declines linearly, reaching zero in the year 2300)

Note: In the fifth scenario, 2000-2100 GDP is equal to the average of the GDP under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

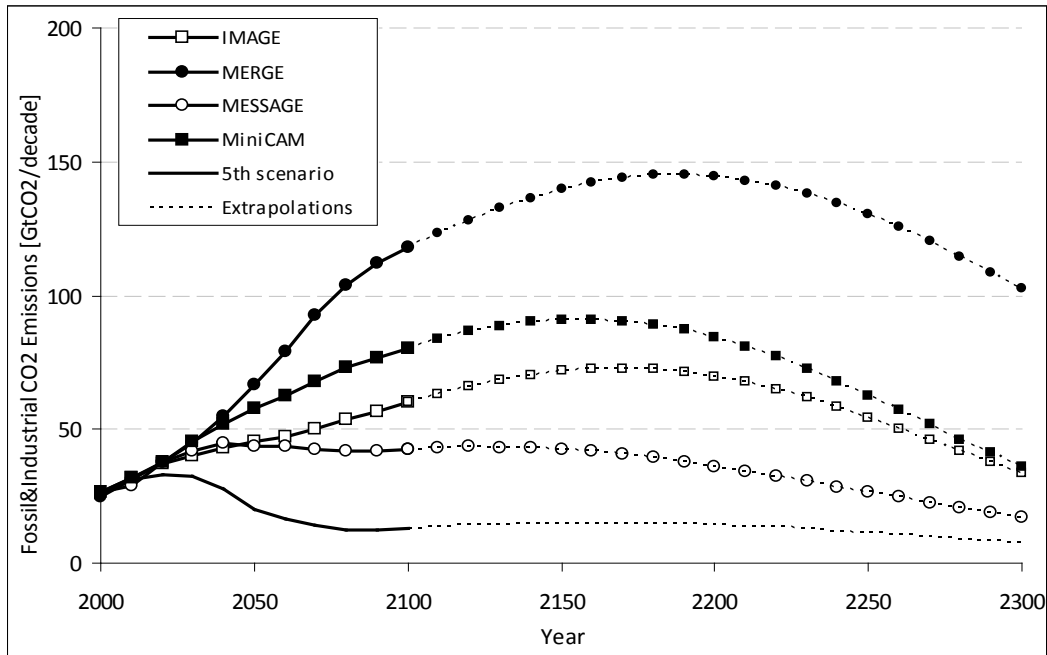


Figure 15A.9.4 Global Fossil and Industrial CO₂ Emissions, 2000-2300 (Post-2100 extrapolations assume growth rate of CO₂ intensity (CO₂/GDP) over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

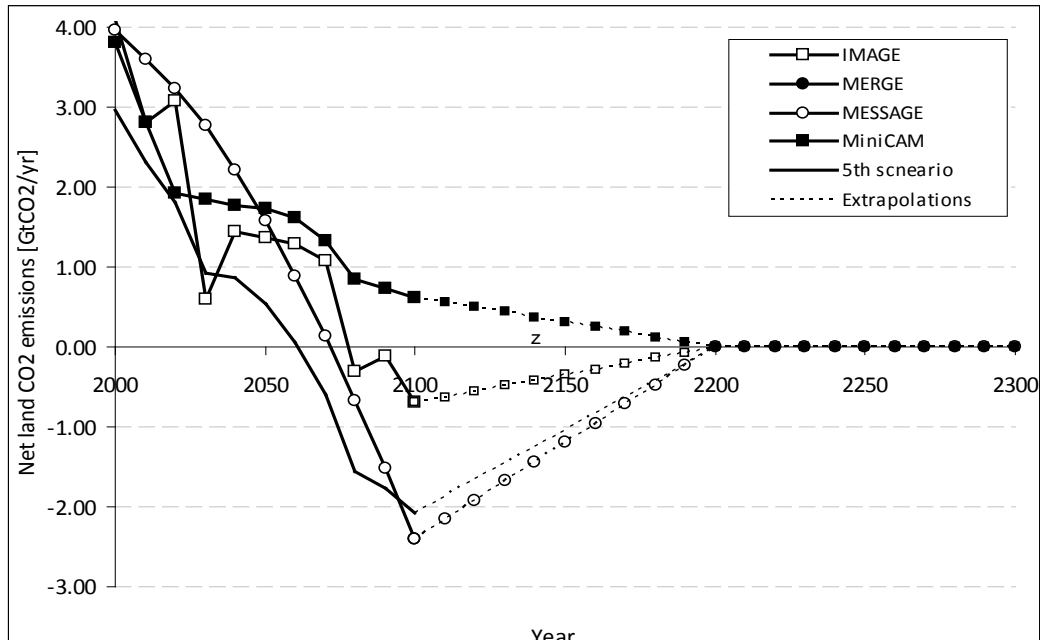


Figure 15A.9.5 Global Net Land Use CO₂ Emissions, 2000-2300 (Post-2100 extrapolations assume emissions decline linearly, reaching zero in the year 2200)^{kk}

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

^{kk} MERGE assumes a neutral biosphere so net land CO₂ emissions are set to zero for all years for the MERGE Optimistic reference scenario, and for the MERGE component of the average 550 scenario (i.e., we add up the land use emissions from the other three models and divide by 4).

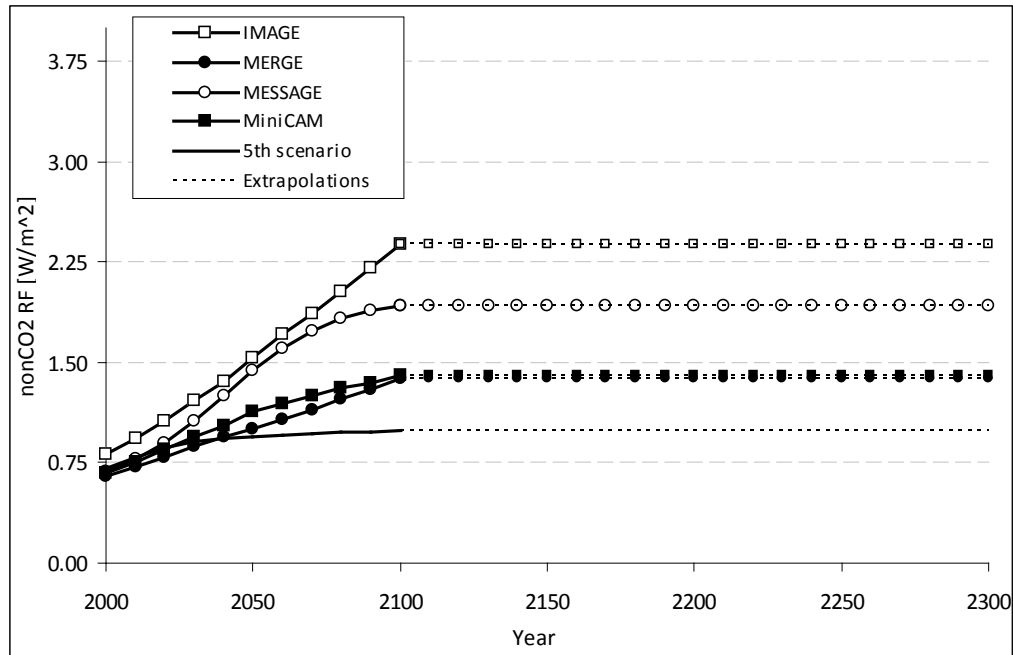


Figure 15A.9.6 Global Non-CO₂ Radiative Forcing, 2000-2300 (Post-2100 extrapolations assume constant non-CO₂ radiative forcing after 2100)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

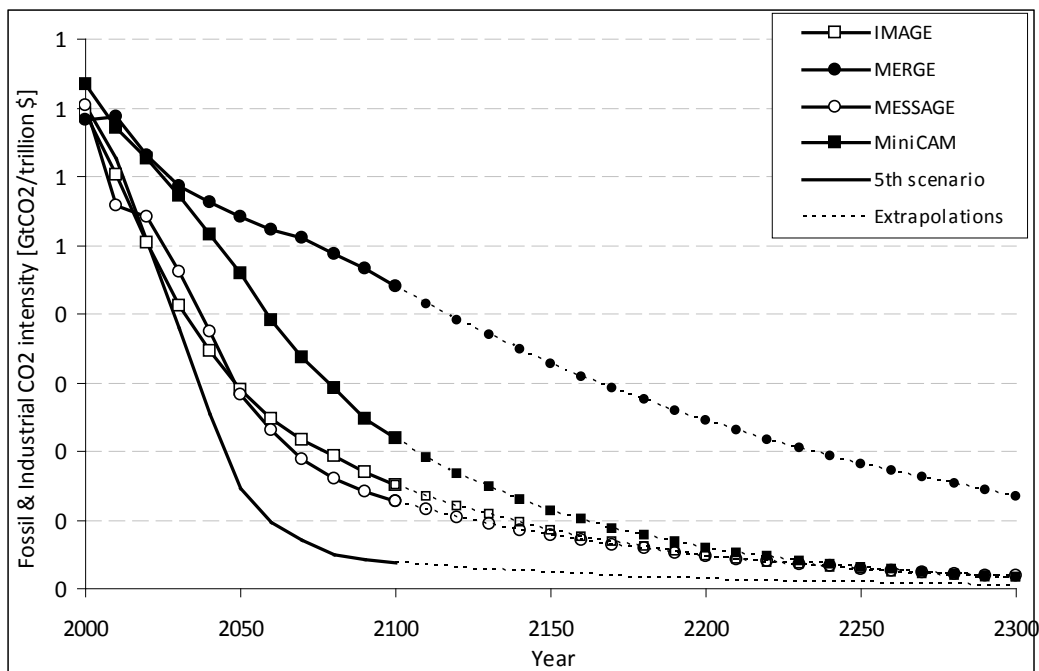


Figure 15A.9.7 Global CO₂ Intensity (fossil & industrial CO₂ emissions/GDP), 2000-2300 (Post-2100 extrapolations assume decline in CO₂/GDP growth rate over 2090-2100 is maintained through 2300)

Note: In the fifth scenario, 2000-2100 emissions are equal to the average of the emissions under the 550 ppm CO₂e, full-participation, not-to-exceed scenarios considered by each of the four models.

Table 15A.9.2 2010 Global SCC Estimates at 2.5 Percent Discount Rate (2007\$/ton CO₂)

<i>Percentile</i>	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
<i>Scenario</i>	PAGE									
IMAGE	3.3	5.9	8.1	13.9	28.8	65.5	68.2	147.9	239.6	563.8
MERGE optimistic	1.9	3.2	4.3	7.2	14.6	34.6	36.2	79.8	124.8	288.3
Message	2.4	4.3	5.8	9.8	20.3	49.2	50.7	114.9	181.7	428.4
MiniCAM base	2.7	4.6	6.4	11.2	22.8	54.7	55.7	120.5	195.3	482.3
5th scenario	2.0	3.5	4.7	8.1	16.3	42.9	41.5	103.9	176.3	371.9

<i>Scenario</i>	DICE									
IMAGE	16.4	21.4	25	33.3	46.8	54.2	69.7	96.3	111.1	130.0
MERGE optimistic	9.7	12.6	14.9	19.7	27.9	31.6	40.7	54.5	63.5	73.3
Message	13.5	17.2	20.1	27	38.5	43.5	55.1	75.8	87.9	103.0
MiniCAM base	13.1	16.7	19.8	26.7	38.6	44.4	56.8	79.5	92.8	109.3
5th scenario	10.8	14	16.7	22.2	32	37.4	47.7	67.8	80.2	96.8

<i>Scenario</i>	FUND									
IMAGE	-33.1	-18.9	-13.3	-5.5	4.1	19.3	18.7	43.5	67.1	150.7
MERGE optimistic	-33.1	-14.8	-10	-3	5.9	14.8	20.4	43.9	65.4	132.9
Message	-32.5	-19.8	-14.6	-7.2	1.5	8.8	13.8	33.7	52.3	119.2
MiniCAM base	-31.0	-15.9	-10.7	-3.4	6	22.2	21	46.4	70.4	152.9
5th scenario	-32.2	-21.6	-16.7	-9.7	-2.3	3	6.7	20.5	34.2	96.8

Table 15A.9.3 2010 Global SCC Estimates at 3 Percent Discount Rate (2007\$/ton CO₂)

<i>Percentile</i>	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
<i>Scenario</i>	PAGE									
IMAGE	2.0	3.5	4.8	8.1	16.5	39.5	41.6	90.3	142.4	327.4
MERGE optimistic	1.2	2.1	2.8	4.6	9.3	22.3	22.8	51.3	82.4	190.0
Message	1.6	2.7	3.6	6.2	12.5	30.3	31	71.4	115.6	263.0
MiniCAM base	1.7	2.8	3.8	6.5	13.2	31.8	32.4	72.6	115.4	287.0
5th scenario	1.3	2.3	3.1	5	9.6	25.4	23.6	62.1	104.7	222.5

<i>Scenario</i>	DICE									
IMAGE	11.0	14.5	17.2	22.8	31.6	35.8	45.4	61.9	70.8	82.1
MERGE optimistic	7.1	9.2	10.8	14.3	19.9	22	27.9	36.9	42.1	48.8
Message	9.7	12.5	14.7	19	26.6	29.8	37.8	51.1	58.6	67.4
MiniCAM base	8.8	11.5	13.6	18	25.2	28.8	36.9	50.4	57.9	67.8
5th scenario	7.9	10.1	11.8	15.6	21.6	24.9	31.8	43.7	50.8	60.6

<i>Scenario</i>	FUND									
IMAGE	-25.2	-15.3	-11.2	-5.6	0.9	8.2	10.4	25.4	39.7	90.3
MERGE optimistic	-24.0	-12.4	-8.7	-3.6	2.6	8	12.2	27	41.3	85.3
Message	-25.3	-16.2	-12.2	-6.8	-0.5	3.6	7.7	20.1	32.1	72.5
MiniCAM base	-23.1	-12.9	-9.3	-4	2.4	10.2	12.2	27.7	42.6	93.0
5th scenario	-24.1	-16.6	-13.2	-8.3	-3	-0.2	2.9	11.2	19.4	53.6

Table 15A.9.4 2010 Global SCC Estimates at 5 Percent Discount Rate (2007\$/ton CO₂)

<i>Percentile</i>	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
<i>Scenario</i>	PAGE									
IMAGE	0.5	0.8	1.1	1.8	3.5	8.3	8.5	19.5	31.4	67.2
MERGE optimistic	0.3	0.5	0.7	1.2	2.3	5.2	5.4	12.3	19.5	42.4
Message	0.4	0.7	0.9	1.6	3	7.2	7.2	17	28.2	60.8
MiniCAM base	0.3	0.6	0.8	1.4	2.7	6.4	6.6	15.9	24.9	52.6
5th scenario	0.3	0.6	0.8	1.3	2.3	5.5	5	12.9	22	48.7

<i>Scenario</i>	DICE									
IMAGE	4.2	5.4	6.2	7.6	10	10.8	13.4	16.8	18.7	21.1
MERGE optimistic	2.9	3.7	4.2	5.3	7	7.5	9.3	11.7	12.9	14.4
Message	3.9	4.9	5.5	7	9.2	9.8	12.2	15.4	17.1	18.8
MiniCAM base	3.4	4.2	4.7	6	7.9	8.6	10.7	13.5	15.1	16.9
5th scenario	3.2	4	4.6	5.7	7.6	8.2	10.2	12.8	14.3	16.0

<i>Scenario</i>	FUND									
IMAGE	-11.7	-8.4	-6.9	-4.6	-2.2	-1.3	0.7	4.1	7.4	17.4
MERGE optimistic	-10.6	-7.1	-5.6	-3.6	-1.3	-0.3	1.6	5.4	9.1	19.0
Message	-12.2	-8.9	-7.3	-4.9	-2.5	-1.9	0.3	3.5	6.5	15.6
MiniCAM base	-10.4	-7.2	-5.8	-3.8	-1.5	-0.6	1.3	4.8	8.2	18.0
5th scenario	-10.9	-8.3	-7	-5	-2.9	-2.7	-0.8	1.4	3.2	9.2

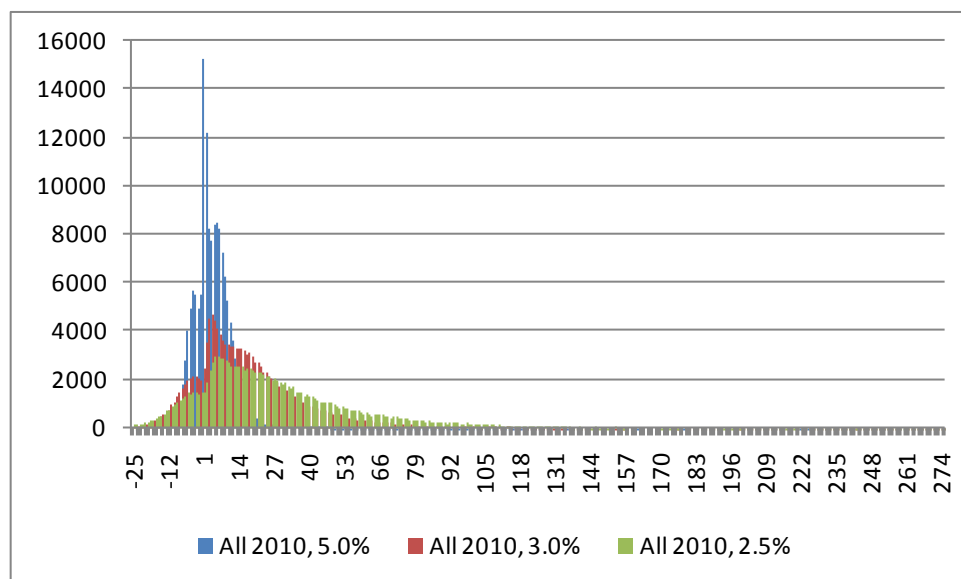


Figure 15A.9.8 Histogram of Global SCC Estimates in 2010 (2007\$/ton CO₂), by discount rate

* The distribution of SCC values ranges from -\$5,192 to \$66,116, but the X-axis has been truncated at approximately the 1st and 99th percentiles to better show the data.

Table 15A.9.5 Additional Summary Statistics of 2010 Global SCC Estimates

Discount Rate		Scenario		
		DICE	PAGE	FUND
5%	Mean	9	6.5	-1.3
	Variance	13.1	136	70.1
	Skewness	0.8	6.3	28.2
	Kurtosis	0.2	72.4	1,479.00
3%	Mean	28.3	29.8	6
	Variance	209.8	3,383.70	16,382.50
	Skewness	1.1	8.6	128
	Kurtosis	0.9	151	18,976.50
2.50%	Mean	42.2	49.3	13.6
	Variance	534.9	9,546.00	#####
	Skewness	1.2	8.7	149
	Kurtosis	1.1	143.8	23,558.30

APPENDIX 15B. TECHNICAL UPDATE OF SOCIAL COST OF CARBON FOR REGULATORY IMPACT ANALYSIS UNDER EXECUTIVE ORDER 12866

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15B.1 PREFACE

The following text is reproduced almost verbatim from the May 2013 report (revised November 2013) of the Interagency Working Group on the Social Cost of Carbon of the United States Government.^a Minor changes were made to the working group's report to make it more consistent with the rest of this technical support document. Annex B describes the revisions that were made to the May 2013 report.

15B.2 PURPOSE

The purpose of this document is to update the schedule of social cost of carbon (SCC)^b estimates from the 2010 interagency technical support document (TSD) (Interagency Working Group on Social Cost of Carbon 2010).¹ E.O. 13563 commits the Administration to regulatory decision making “based on the best available science.”^c Additionally, the interagency group recommended in 2010 that the SCC estimates be revisited on a regular basis or as model updates that reflect the growing body of scientific and economic knowledge become available.^d New versions of the three integrated assessment models used by the U.S. government to estimate the SCC (DICE, FUND, and PAGE), are now available and have been published in the peer reviewed literature. While acknowledging the continued limitations of the approach taken by the interagency group in 2010 (documented in the original 2010 TSD), this document provides an update of the SCC estimates based solely on the latest peer-reviewed version of the models, replacing model versions that were developed up to ten years ago in a rapidly evolving field. It does not revisit other assumptions with regard to the discount rate, reference case socioeconomic and emission scenarios, or equilibrium climate sensitivity. Improvements in the way damages are modeled are confined to those that have been incorporated into the latest versions of the models by the developers themselves in the peer-reviewed literature. The Environmental Protection Agency (EPA), in collaboration with other Federal agencies such as the Department of Energy (DOE), continues to investigate potential improvements to the way in which economic damages associated with changes in CO₂ emissions are quantified.

Section 3 summarizes the major updates relevant to SCC estimation that are contained in the new versions of the integrated assessment models released since the 2010 interagency report. Section 4 presents the updated schedule of SCC estimates for 2010 – 2050 based on these versions of the models. Section 5 provides a discussion of recent workshops to support improvements in SCC estimation.

^a Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. Interagency Working Group on Social Cost of Carbon, United States Government. May 2013; revised November 2013. <http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf>

^b In this document, we present all values of the SCC as the cost per metric ton of CO₂ emissions. Alternatively, one could report the SCC as the cost per metric ton of carbon emissions. The multiplier for translating between mass of CO₂ and the mass of carbon is 3.67.

^c http://www.whitehouse.gov/sites/default/files/omb/inforeg/eo12866/eo13563_01182011.pdf

^d See p. 1, 3, 4, 29, and 33 (Interagency Working Group on Social Cost of Carbon 2010).¹

15B.3 SUMMARY OF MODEL UPDATES

This section briefly summarizes changes integrated into the most recent versions of the three integrated assessment models (IAMs) used by the interagency group in 2010. We focus on describing those model updates that are relevant to estimating the social cost of carbon. For example, both the DICE and PAGE models now include an explicit representation of sea level rise damages. Other revisions to PAGE include: updated adaptation assumptions, revisions to ensure damages are constrained GDP, updated regional scaling of damages, and a revised treatment of potentially abrupt shifts in climate damages. In the most recent version of DICE, the model's simple carbon cycle has been updated to be more consistent with a relatively more complex climate model. The FUND model includes updated damage functions for sea level rise impacts, the agricultural sector, and reduced space heating requirements, as well as changes to the response of temperature to the buildup of GHG concentrations and the inclusion of indirect effects of methane emissions. Changes made to parts of the models that are superseded by the interagency working group's modeling assumptions – regarding climate sensitivity, discounting, and socioeconomic variables – are not discussed.

15B.3.1 DICE

Changes in the DICE model relevant for the SCC estimates developed by the interagency working group include: 1) updated parameter values for the carbon cycle model, 2) an explicit representation of sea level dynamics, and 3) a re-calibrated damage function that includes an explicit representation of economic damages from sea level rise. Changes were also made to other parts of the DICE model—including the equilibrium climate sensitivity parameter, the rate of change of total factor productivity, and the elasticity of the marginal utility of consumption—but these components of DICE are superseded by the interagency working group's assumptions and so will not be discussed here. More details on DICE2007 can be found in Nordhaus (2008)² and on DICE2010 in Nordhaus (2010)³ and the associated on-line appendix containing supplemental information.

15B.3.1.1 Carbon Cycle Parameters

DICE uses a three-box model of carbon stocks and flows to represent the accumulation and transfer of carbon among the atmosphere, the shallow ocean and terrestrial biosphere, and the deep ocean. These parameters are “calibrated to match the carbon cycle in the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC)” (Nordhaus 2008 p 44).^{2e} Carbon cycle transfer coefficient values in DICE2010 are based on re-calibration of the model to match the newer version of MAGICC (Nordhaus 2010 p 2).³ For example, in DICE2010 in each decade, 12 percent of the carbon in the atmosphere is transferred to the shallow ocean, 4.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 94.8 percent remains in the shallow ocean, and 0.5 percent is transferred to the deep ocean. For comparison, in DICE 2007, 18.9 percent of the carbon in the atmosphere is transferred to the shallow ocean each

^e MAGICC is a simple climate model initially developed within the U.S. National Center for Atmospheric Research that has been used heavily by the Intergovernmental Panel on Climate Change (IPCC) to emulate projections from much more sophisticated state of the art earth system simulation models (Randall et al. 2007).⁴

decade, 9.7 percent of the carbon in the shallow ocean is transferred to the atmosphere, 85.3 percent remains in the shallow ocean, and 5 percent is transferred to the deep ocean.

The implication of these changes for DICE2010 is in general a weakening of the ocean as a carbon sink and therefore a higher concentration of carbon in the atmosphere than in DICE2007, for a given path of emissions. All else equal, these changes will generally increase the level of warming and therefore the SCC estimates in DICE2010 relative to those from DICE2007.

15B.3.1.2 Sea Level Dynamics

A new feature of DICE2010 is an explicit representation of the dynamics of the global average sea level anomaly to be used in the updated damage function (discussed below). This section contains a brief description of the sea level rise (SLR) module; a more detailed description can be found on the model developer's website.^f The average global sea level anomaly is modeled as the sum of four terms that represent contributions from: 1) thermal expansion of the oceans, 2) melting of glaciers and small ice caps, 3) melting of the Greenland ice sheet, and 4) melting of the Antarctic ice sheet.

The parameters of the four components of the SLR module are calibrated to match consensus results from the IPCC's Fourth Assessment Report.^{4 g} The rise in sea level from thermal expansion in each time period (decade) is 2 percent of the difference between the sea level in the previous period and the long run equilibrium sea level, which is 0.5 meters per degree Celsius (°C) above the average global temperature in 1900. The rise in sea level from the melting of glaciers and small ice caps occurs at a rate of 0.008 meters per decade per °C above the average global temperature in 1900.

The contribution to sea level rise from melting of the Greenland ice sheet is more complex. The equilibrium contribution to SLR is 0 meters for temperature anomalies less than 1 °C and increases linearly from 0 meters to a maximum of 7.3 meters. The contribution to SLR in each period is proportional to the difference between the previous period's sea level anomaly and the equilibrium sea level anomaly, where the constant of proportionality increases with the temperature anomaly in the current period.

The contribution to SLR from the melting of the Antarctic ice sheet is -0.001 meters per decade when the temperature anomaly is below 3 °C and increases linearly to a maximum rate of 0.025 meters per decade at a temperature anomaly of 6 °C.

15B.3.1.3 Re-calibrated Damage Function

Economic damages from climate change in the DICE model are represented by a fractional loss of gross economic output in each period. A portion of the remaining economic

^f Documentation on the new sea level rise module of DICE is available on William Nordhaus' website at: http://nordhaus.econ.yale.edu/documents/SLR_021910.pdf.

^g For a review of post-IPCC AR4 research on sea level rise, see Nicholls et al. (2011)⁵ and NAS (2011).⁶

output in each period (net of climate change damages) is consumed and the remainder is invested in the physical capital stock to support future production, so each period's climate damages will reduce consumption in that period and in all future periods due to the lost investment. The fraction of output in each period that is lost due to climate change impacts is represented as one minus a fraction, which is one divided by a quadratic function of the temperature anomaly, producing a sigmoid ("S"-shaped) function. The loss function in DICE2010 has been expanded by adding a quadratic function of SLR to the quadratic function of temperature. In DICE2010 the temperature anomaly coefficients have been recalibrated to avoid double-counting damages from sea level rise that were implicitly included in these parameters in DICE2007.

The aggregate damages in DICE2010 are illustrated by Nordhaus (2010 p 3),³ who notes that "...damages in the uncontrolled (baseline) [i.e., reference] case ... in 2095 are \$12 trillion, or 2.8 percent of global output, for a global temperature increase of 3.4 °C above 1900 levels." This compares to a loss of 3.2 percent of global output at 3.4 °C in DICE2007. However, in DICE2010 (as downloaded from the homepage of William Nordhaus), annual damages are lower in most of the early periods but higher in later periods of the time horizon than would be calculated using the DICE2007 damage function. Specifically, the percent difference between damages in the base run of DICE2010 and those that would be calculated using the DICE2007 damage function starts at +7 percent in 2005, decreases to a low of -14 percent in 2065, then continuously increases to +20 percent by 2300 (the end of the interagency analysis time horizon), and to +160 percent by the end of the model time horizon in 2595. The large increases in the far future years of the time horizon are due to the permanence associated with damages from sea level rise, along with the assumption that the sea level is projected to continue to rise long after the global average temperature begins to decrease. The changes to the loss function generally decrease the interagency working group SCC estimates slightly, all else equal.

15B.3.2 FUND

FUND version 3.8 includes a number of changes over the previous version 3.5 used in the interagency report. Documentation supporting FUND and the model's source code for all versions of the model is available from the model authors.^h Notable changes, due to their impact on the estimates of expected SCC, are adjustments to the space heating, agriculture, and sea level rise damage functions in addition to changes to the temperature response function and the inclusion of indirect effects from methane emissions.ⁱ We discuss each of these in turn.

^h <http://www.fund-model.org/>. This report uses version 3.8 of the FUND model, which represents a modest update to the most recent version of the model to appear in the literature (version 3.7) (Anthoff and Tol, 2013).⁷ For the purpose of computing the SCC, the relevant changes are associated with improving consistency with IPCC AR4 by adjusting the atmospheric lifetimes of CH₄ and N₂O and incorporating the indirect forcing effects of CH₄, along with making minor stability improvements in the sea wall construction algorithm.

ⁱ The other damage sectors (water resources, space cooling, land loss, migration, ecosystems, human health, and extreme weather) were not the subject of significant updates.

15B.3.2.1 Space Heating

In FUND, the damages associated with the change in energy needs for space heating are based on the estimated impact due to one degree of warming. These baseline damages are scaled based on the forecasted temperature anomaly's deviation from the one degree benchmark and adjusted for changes in vulnerability due to economic and energy efficiency growth. In FUND 3.5, the function that scales the base year damages adjusted for vulnerability allows for the possibility that in some simulations the benefits associated with reduced heating needs may be an unbounded convex function of the temperature anomaly. In FUND 3.8, the form of the scaling has been modified to ensure that the function is everywhere concave, meaning that for every simulation there will exist an upper bound on the benefits a region may receive from reduced space heating needs. The new formulation approaches a value of two in the limit as the temperature anomaly increases, or in other words, assuming no decrease in vulnerability, the reduced expenditures on space heating at any level of warming will not exceed two times the reductions experienced at one degree of warming. Since the reduced need for space heating represents a benefit of climate change in the model, or a negative damage, this change will increase the estimated SCC. This update accounts for a significant portion of the difference in the expected SCC estimates reported by the two versions of the model when run probabilistically.

15B.3.2.2 Sea Level Rise and Land Loss

The FUND model explicitly includes damages associated with the inundation of dry land due to sea level rise. The amount of land lost within a region is dependent upon the proportion of the coastline being protected by adequate sea walls and the amount of sea level rise. In FUND 3.5 the function defining the potential land lost in a given year due to sea level rise is linear in the rate of sea level rise for that year. This assumption implicitly assumes that all regions are well represented by a homogeneous coastline in length and a constant uniform slope moving inland. In FUND 3.8 the function defining the potential land lost has been changed to be a non-linear function of sea level rise, thereby assuming that the slope of the shore line is not constant moving inland, with a positive first derivative. The effect of this change is to typically reduce the vulnerability of some regions to sea level rise based land loss, therefore having an effect of lowering the expected SCC estimate. The model has also been updated to assume that the value of dry land at risk of inundation is not uniform across a region but will be a decreasing function of protection measure, thereby implicitly assuming that the most valuable land will be protected first.

15B.3.2.3 Agriculture

In FUND, the damages associated with the agricultural sector are measured as proportional to the sector's value. The fraction is made up of three additively separable components that represent the effects from carbon fertilization, the rate of temperature change, and the level of the temperature anomaly. In both FUND 3.5 and FUND 3.8, the fraction of the sector's value lost due to the level of the temperature anomaly is modeled as a quadratic function with an intercept of zero. In FUND 3.5, the linear and quadratic coefficients are modeled as the ratio of two normal distributions. Within this specification, as draws from the distribution in the denominator approached zero the share of the sector's value "lost" approaches (+/-) infinity

independent of the temperature anomaly itself. In FUND 3.8, the linear and quadratic coefficients are drawn directly from truncated normal distributions so that they remain in the range $[0, \infty)$ and $(-\infty, 0]$, respectively, where the means for the new distributions are set equal to the ratio of the means from the normal distributions used in the previous version. In general the impact of this change has been to increase the likelihood that increases in the temperature level will have either larger positive or negative effects on the agricultural sector relative to the previous version (through eliminating simulations in which the “lost” value approached $(+/-)$ infinity). The net effect of this change on the SCC estimates is difficult to predict.

15B.3.2.4 Temperature Response Model

The temperature response model translates changes in global levels of radiative forcing into the current expected temperature anomaly. In FUND, a given year’s increase in the cumulative temperature anomaly is based on a mean reverting function where the mean equals the equilibrium temperature anomaly that would eventually be reached if that year’s level of radiative forcing were sustained. The rate of mean reversion defines the rate at which the transient temperature approaches the equilibrium. In FUND 3.5, the rate of temperature response is defined as a decreasing linear function of equilibrium climate sensitivity to capture the fact that the progressive heat uptake of the deep ocean causes the rate to slow at higher values of the equilibrium climate sensitivity. In FUND 3.8, the rate of temperature response has been updated to a quadratic function of the equilibrium climate sensitivity. This change reduces the sensitivity of the rate of temperature response to the level of the equilibrium climate sensitivity. Therefore in FUND 3.8, the temperature response will typically be faster than in the previous version. The overall effect of this change is likely to increase estimates of the SCC as higher temperatures are reached during the timeframe analyzed and as the same damages experienced in the previous version of the model are now experienced earlier and therefore discounted less.

15B.3.2.5 Methane

The IPCC notes a series of indirect effects of methane emissions, and has developed methods for proxying such effects when computing the global warming potential of methane (Forster et al. 2007).⁸ FUND 3.8 now includes the same methods for incorporating the indirect effects of methane emissions. Specifically, the average atmospheric lifetime of methane has been set to 12 years to account for the feedback of CH₄ emissions on its own lifetime. The radiative forcing associated with atmospheric methane has also been increased by 40% to account for its net impact on ozone production and increase in stratospheric water vapor. The general effect of this increased radiative forcing will be to increase the estimated SCC values, where the degree to which this occurs will be dependent upon the relative curvature of the damage functions with respect to the temperature anomaly.

15B.3.3 PAGE

PAGE09 (Hope 2012)⁹ includes a number of changes from PAGE2002, the version used in the 2009 SCC interagency report. The changes that most directly affect the SCC estimates include: explicitly modeling the impacts from sea level rise, revisions to the damage function to ensure damages are constrained by GDP, a change in the regional scaling of damages, a revised

treatment for the probability of a discontinuity within the damage function, and revised assumptions on adaptation. The model also includes revisions to the carbon cycle feedback and the calculation of regional temperatures. More details on PAGE2009 can be found in three working papers (Hope 2011a, 2011b, 2011c).^{10, 11, 12} A description of PAGE2002 can be found in Hope (2006).¹³

15B.3.3.1 Sea Level Rise

While PAGE2002 aggregates all damages into two categories – economic and non-economic impacts - PAGE2009 adds a third explicit category: damages from sea level rise. In the previous version of the model, damages from sea level rise were subsumed by the other damage categories. PAGE09 models damages from sea level rise as increasing less than linearly with sea level based on the assumption that low-lying shoreline areas will be associated with higher damages than current inland areas. Damages from the economic and non-economic sector were adjusted to account for the introduction of this new category.

15B.3.3.2 Revised Damage Function to Account for Saturation

In PAGE09, small initial economic and non-economic benefits (negative damages) are modeled for small temperature increases, but all regions eventually experience positive economic damages from climate change, where damages are the sum of additively separable polynomial functions of temperature and sea level rise. Damages transition from this polynomial function to a logistic path once they exceed a certain proportion of remaining Gross Domestic Product (GDP) to ensure that damages do not exceed 100 percent of GDP. This differs from PAGE2002, which allowed Eastern Europe to potentially experience large benefits from temperature increases, and which also did not bound the possible damages that could be experienced.

15B.3.3.3 Regional Scaling Factors

As in the previous version of PAGE, the PAGE09 model calculates the damages for the European Union (EU) and then, assumes that damages for other regions are proportional based on a given scaling factor. The scaling factor in PAGE09 is based on the length of a region's coastline relative to the EU (Hope 2011b).¹¹ Because of the long coastline in the EU, other regions are, on average, less vulnerable than the EU for the same sea level and temperature increase, but all regions have a positive scaling factor. PAGE2002 based its scaling factors on four studies reported in the IPCC's third assessment report, and allowed for benefits from temperature increase in Eastern Europe, smaller impacts in developing countries, and higher damages in developing countries.

15B.3.3.4 Probability of a Discontinuity

In PAGE2002, the damages associated with a “discontinuity” were modeled as an expected value. That is, additional damages from an extreme event, such as extreme melting of the Greenland ice sheet, were multiplied by the probability of the event occurring and added to the damage estimate. In PAGE09, the probability of “discontinuity” is treated as a discrete event for each year in the model. The damages for each model run are estimated either with or without

a discontinuity occurring, rather than as an expected value. A large-scale discontinuity becomes possible when the temperature rises beyond some threshold value between 2 and 4°C. The probability that a discontinuity will occur beyond this threshold then increases by between 10 and 30 percent for every 1°C rise in temperature beyond the threshold. If a discontinuity occurs, the EU loses an additional 5 to 25 percent of its GDP (drawn from a triangular distribution with a mean of 15 percent) in addition to other damages, and other regions lose an amount determined by the regional scaling factor. The threshold value for a possible discontinuity is lower than in PAGE2002, while the rate at which the probability of a discontinuity increases with the temperature anomaly and the damages that result from a discontinuity are both higher than in PAGE2002. The model assumes that only one discontinuity can occur and that the impact is phased in over a period of time, but once it occurs, its effect is permanent.

15B.3.3.5 Adaptation

As in PAGE2002, adaptation is available to increase the tolerable level of temperature change and can help mitigate any climate change impacts that still occur. In PAGE this adaptation is the same regardless of the temperature change or sea level rise and is therefore akin to what is more commonly considered a reduction in vulnerability. It is modeled by modifying the temperature change and sea level rise used in the damage function or by reducing the damages by some percentage. PAGE09 assumes a smaller decrease in vulnerability than the previous version of the model and assumes that it will take longer for this change in vulnerability to be realized. In the aggregated economic sector, at the time of full implementation, this adaptation will mitigate all damages up to a temperature increase of 1°C, and for temperature anomalies between 1°C and 3°C, it will reduce damages by 15-30 percent (depending on the region). However, it takes 20 years to fully implement this adaptation. In PAGE2002, adaptation was assumed to reduce economic sector damages up to 3°C by 50-90 percent after 20 years. Beyond 3°C, no adaptation is assumed to be available to mitigate the impacts of climate change. For the non-economic sector, in PAGE09 adaptation is available to reduce 15 percent of the damages due to a temperature increase between 0°C and 2°C and is assumed to take 40 years to fully implement, instead of 25 percent of the damages over 20 years assumed in PAGE2002. Similarly, adaptation is assumed to alleviate 25-50 percent of the damages from the first 0.20 to 0.25 meters of sea level rise but is assumed to be ineffective thereafter. Hope (2011c)¹² estimates that the less optimistic assumptions regarding the ability to offset impacts of temperature and sea level rise via adaptation increase the SCC by approximately 30 percent.

15B.3.3.6 Other Noteworthy Changes

Two other changes in the model are worth noting. A revised carbon cycle feedback is introduced to simulate decreased CO₂ absorption by the terrestrial biosphere and ocean as the temperature rises. This feedback is linear in the average global and annual temperature anomaly but is capped at a maximum value. In the previous version of PAGE, an additional amount was added to the CO₂ emissions each period to account for a decrease in ocean absorption and a loss of soil carbon. Also updated is the method by which the average global and annual temperature anomaly is downscaled to determine annual average regional temperature anomalies to be used in the regional damage functions. In the previous version of PAGE, the scaling was determined solely based on regional difference in emissions of sulfate aerosols. In PAGE09, this regional

temperature anomaly is further adjusted using an additive factor that is based on the average absolute latitude of a region relative to the area weighted average absolute latitude of the Earth's landmass.

15B.4 REVISED SCC ESTIMATES

The updated versions of the three integrated assessment models were run using the same methodology detailed in the 2010 TSD.¹ The approach along with the inputs for the socioeconomic emissions scenarios, equilibrium climate sensitivity distribution, and discount rate remains the same. This includes the five reference scenarios based on the EMF-22 modeling exercise, the Roe and Baker equilibrium climate sensitivity distribution calibrated to the Fourth Assessment Report of the IPCC, and three constant discount rates of 2.5, 3, and 5 percent.

As was previously the case, the use of three models, three discount rates, and five scenarios produces 45 separate distributions for the SCC. The approach laid out in the TSD applied equal weight to each model and socioeconomic scenario in order to reduce the dimensionality down to three separate distributions representative of the three discount rates. The interagency group selected four values from these distributions for use in regulatory analysis. Three values are based on the average SCC across models and socio-economic-emissions scenarios at the 2.5, 3, and 5 percent discount rates, respectively. The fourth value was chosen to represent the higher-than-expected economic impacts from climate change further out in the tails of the SCC distribution. For this purpose, the 95th percentile of the SCC estimates at a 3 percent discount rate was chosen. (A detailed set of percentiles by model and scenario combination is available in the Annex.) As noted in the original TSD, “the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate” (TSD, p. 25). However, for purposes of capturing the uncertainties involved in regulatory impact analysis, the interagency group emphasizes the importance and value of including all four SCC values.

0 shows the four selected SCC estimates in five year increments from 2010 to 2050. Values for 2010, 2020, 2030, 2040, and 2050 are calculated by first combining all outputs (10,000 estimates per model run) from all scenarios and models for a given discount rate. Values for the years in between are calculated using basic linear interpolation. The full set of annual SCC estimates between 2010 and 2050 is reported in the Annex.

Table 15B.4.1 Revised Social Cost of CO₂, 2010 – 2050 (in 2007 dollars per ton of CO₂)

Discount Rate	5.0%	3.0%	2.5%	3.0%
Year	Avg	Avg	Avg	95th
2010	11	32	51	89
2015	11	37	57	109
2020	12	43	64	128
2025	14	47	69	143
2030	16	52	75	159
2035	19	56	80	175
2040	21	61	86	191
2045	24	66	92	206
2050	26	71	97	220

The SCC estimates using the updated versions of the models are higher than those reported in the TSD due to the changes to the models outlined in the previous section. Figure 15B.4.1 illustrates where the four SCC values for 2020 fall within the full distribution for each discount rate based on the combined set of runs for each model and scenario (150,000 estimates in total for each discount rate). In general, the distributions are skewed to the right and have long tails. The Figure also shows that the lower the discount rate, the longer the right tail of the distribution.

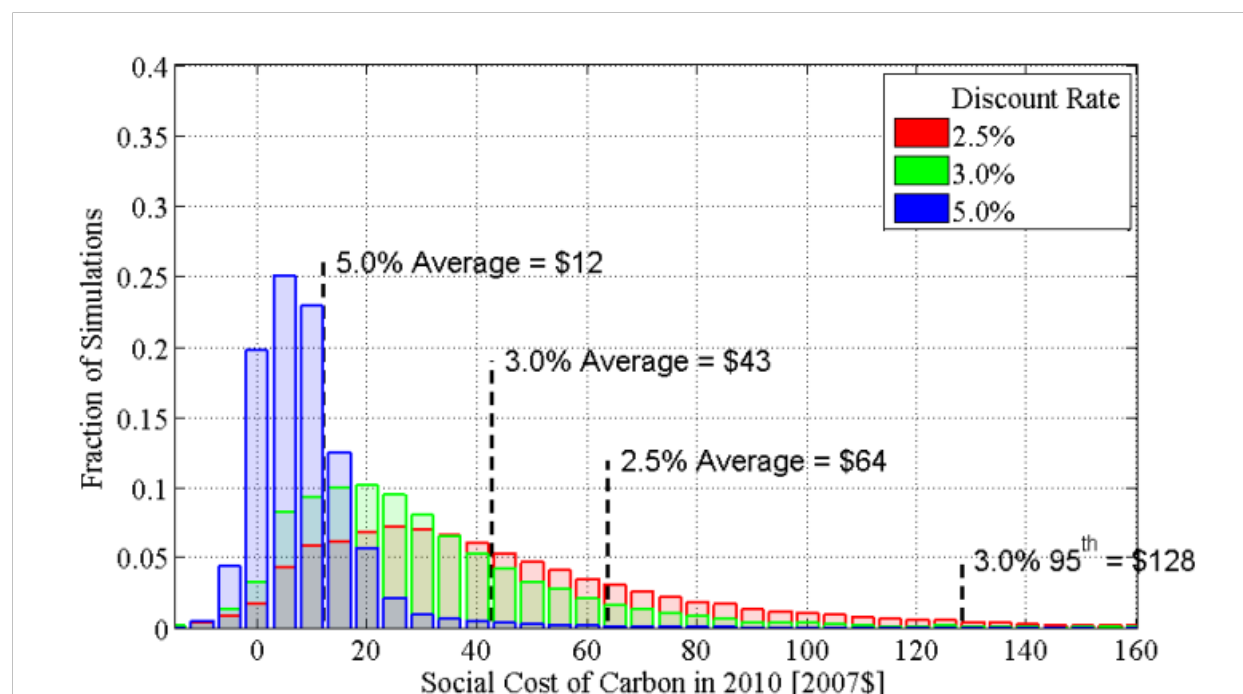


Figure 15B.4.1 Distribution of SCC Estimates for 2020 (in 2007\$ per ton CO₂)

As was the case in the original TSD, the SCC increases over time because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change. The approach taken by the interagency group is to allow the growth rate to be determined endogenously by the models

through running them for a set of perturbation years out to 2050. 0 illustrates how the growth rate for these four SCC estimates varies over time.

Table 15B.4.2 Average Annual Growth Rates of SCC Estimates between 2010 and 2050

Average Annual Rate (%)	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010-2020	1.2%	3.3%	2.4%	4.4%
2020-2030	3.4%	2.1%	1.7%	2.4%
2030-2040	3.0%	1.9%	1.5%	2.1%
2040-2050	2.6%	1.6%	1.3%	1.5%

The future monetized value of emission reductions in each year (the SCC in year t multiplied by the change in emissions in year t) must be discounted to the present to determine its total net present value for use in regulatory analysis. As previously discussed in the original TSD, damages from future emissions should be discounted at the same rate as that used to calculate the SCC estimates themselves to ensure internal consistency – i.e., future damages from climate change, whether they result from emissions today or emissions in a later year, should be discounted using the same rate.

15B.5 OTHER MODEL LIMITATIONS OR RESEARCH GAPS

The 2010 interagency SCC technical support report discusses a number of important limitations for which additional research is needed. In particular, the document highlights the need to improve the quantification of both non-catastrophic and catastrophic damages, the treatment of adaptation and technological change, and the way in which inter-regional and inter-sectoral linkages are modeled. It also discusses the need to more carefully assess the implications of risk aversion for SCC estimation as well as the inability to perfectly substitute between climate and non-climate goods at higher temperature increases, both of which have implications for the discount rate used. EPA, DOE, and other agencies continue to engage in long-term research work on modeling and valuation of climate impacts that we expect will inform improvements in SCC estimation in the future.

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15B.6 ANNEX A

Table 15B.6.1 Annual SCC Values: 2010-2050 (2007\$/ton CO₂)

Discount Rate Year	5.0% Avg	3.0% Avg	2.5% Avg	3.0% 95th
2010	11	32	51	89
2011	11	33	52	93
2012	11	34	54	97
2013	11	35	55	101
2014	11	36	56	105
2015	11	37	57	109
2016	12	38	59	112
2017	12	39	60	116
2018	12	40	61	120
2019	12	42	62	124
2020	12	43	64	128
2021	12	43	65	131
2022	13	44	66	134
2023	13	45	67	137
2024	14	46	68	140
2025	14	47	69	143
2026	15	48	70	146
2027	15	49	71	149
2028	15	50	72	152
2029	16	51	73	155
2030	16	52	75	159
2031	17	52	76	162
2032	17	53	77	165
2033	18	54	78	168
2034	18	55	79	172
2035	19	56	80	175
2036	19	57	81	178
2037	20	58	83	181
2038	20	59	84	185
2039	21	60	85	188
2040	21	61	86	191
2041	22	62	87	194
2042	22	63	88	197
2043	23	64	89	200
2044	23	65	90	203
2045	24	66	92	206
2046	24	67	93	209
2047	25	68	94	211
2048	25	69	95	214
2049	26	70	96	217
2050	26	71	97	220

Table 15B.6.2 2020 Global SCC Estimates at 2.5 Percent Discount Rate (2007\$/ton CO₂)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95 th	99th
Scenario	PAGE									
IMAGE	6	11	15	27	58	129	139	327	515	991
MERGE	4	6	9	16	34	78	82	196	317	649
MESSAGE	4	8	11	20	42	108	107	278	483	918
MiniCAM Base	5	9	12	22	47	107	113	266	431	872
5th Scenario	2	4	6	11	25	85	68	200	387	955

Scenario	DICE									
IMAGE	25	31	37	47	64	72	92	123	139	161
MERGE	14	18	20	26	36	40	50	65	74	85
MESSAGE	20	24	28	37	51	58	71	95	109	221
MiniCAM Base	20	25	29	38	53	61	76	102	117	135
5th Scenario	17	22	25	33	45	52	65	91	106	126

Scenario	FUND									
IMAGE	-14	-2	4	15	31	39	55	86	107	157
MERGE	-6	1	6	14	27	35	46	70	87	141
MESSAGE	-16	-5	1	11	24	31	43	67	83	126
MiniCAM Base	-7	2	7	16	32	39	55	83	103	158
5th Scenario	-29	-13	-6	4	16	21	32	53	69	103

Table 15B.6.3 2020 Global SCC Estimates at 3 Percent Discount Rate (2007\$/ton CO₂)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	4	7	10	18	38	91	95	238	385	727
MERGE	2	4	6	11	23	56	58	142	232	481
MESSAGE	3	5	7	13	29	75	74	197	330	641
MiniCAM Base	3	5	8	14	30	73	75	184	300	623
5th Scenario	1	3	4	7	17	58	48	136	264	660

Scenario	DICE									
IMAGE	16	21	24	32	43	48	60	79	90	102
MERGE	10	13	15	19	25	28	35	44	50	58
MESSAGE	14	18	20	26	35	40	49	64	73	83
MiniCAM Base	13	17	20	26	35	39	49	65	73	85
5th Scenario	12	15	17	22	30	34	43	58	67	79

Scenario	FUND									
IMAGE	-13	-4	0	8	18	23	33	51	65	99
MERGE	-7	-1	2	8	17	21	29	45	57	95
MESSAGE	-14	-6	-2	5	14	18	26	41	52	82
MiniCAM Base	-7	-1	3	9	19	23	33	50	63	101
5th Scenario	-22	-11	-6	1	8	11	18	31	40	62

Table 15B.6.4 2020 Global SCC Estimates at 5 Percent Discount Rate (2007\$/ton CO₂)

Percentile	1st	5th	10th	25th	50th	Avg	75th	90th	95th	99th
Scenario	PAGE									
IMAGE	1	2	2	5	10	28	27	71	123	244
MERGE	1	1	2	3	7	17	17	45	75	153
MESSAGE	1	1	2	4	9	24	22	60	106	216
MiniCAM Base	1	1	2	3	8	21	21	54	94	190
5th Scenario	0	1	1	2	5	18	14	41	78	208

Scenario	DICE									
IMAGE	6	8	9	11	14	15	18	22	25	27
MERGE	4	5	6	7	9	10	12	15	16	18
MESSAGE	6	7	8	10	12	13	16	20	22	25
MiniCAM Base	5	6	7	8	11	12	14	18	20	22
5th Scenario	5	6	6	8	10	11	14	17	19	21

Scenario	FUND									
IMAGE	-9	-5	-4	-1	2	3	6	10	14	24
MERGE	-6	-4	-2	0	3	4	6	11	15	26
MESSAGE	-10	-6	-4	-1	1	2	5	9	12	21
MiniCAM Base	-7	-4	-2	0	3	4	6	11	14	25
5th Scenario	-11	-7	-5	-3	0	0	3	5	7	13

15B.7 ANNEX B

The November 2013 revision of this technical support document is based on two corrections to the runs based on the FUND model. First, the potential dry land loss in the algorithm that estimates regional coastal protections was misspecified in the model's computer code. This correction is covered in an erratum to Anthoff and Tol (2013) published in the same journal (*Climatic Change*) in October 2013.¹⁴ Second, the equilibrium climate sensitivity distribution was inadvertently specified as a truncated Gamma distribution (the default in FUND) as opposed to the truncated Roe and Baker distribution as was intended. The truncated Gamma distribution used in the FUND runs had approximately the same mean and upper truncation point, but lower variance and faster decay of the upper tail, as compared to the intended specification based on the Roe and Baker distribution. The differences between the original estimates reported in the May 2013 version of this technical support document and this revision are all one dollar or less.

APPENDIX 18A. REGULATORY IMPACT ANALYSIS: SUPPORTING MATERIALS

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18A.1 INTRODUCTION

This appendix contains sections discussing the following topics:

- Projections of annual market share increases for the alternative policies;
- NIA-RIA Integrated Model;
- XENERGY penetration curves used to analyze consumer rebates, including:
 - Background material,
 - DOE's adjustment of these curves for this analysis, and
 - The method DOE used to interpolate the curves;
- Detailed tables of rebates offered for the considered lamp types;
- Statistical analysis DOE performed to estimate rebate values; and
- Background material on Federal and state tax credits for appliances.

18A.2 MARKET SHARE ANNUAL INCREASES BY POLICY

Table 18A.2.1 and Table 18A.2.2 show the annual increases in market shares of General Service Fluorescent Lamps (GSFL) meeting the target efficiency levels for the proposed TSL (TSL 5). DOE used these market share increases as inputs to the NIA-RIA spreadsheet model.

Table 18A.2.1 Annual Increases in Market Shares Attributable to Alternative Policy Measures for General Service Fluorescent Lamps (T8 4-ft Medium Bipin)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2017	6.8%	4.1%	2.0%	7.3%	0.1%
2018	6.8%	4.1%	2.0%	12.4%	0.2%
2019	6.8%	4.1%	2.0%	16.8%	0.4%
2020	6.8%	4.1%	2.0%	20.5%	0.5%
2021	6.8%	4.1%	2.0%	23.7%	0.6%
2022	6.8%	4.1%	2.0%	28.2%	0.7%
2023	6.8%	4.1%	2.0%	35.7%	0.9%
2024	6.8%	4.1%	2.0%	42.1%	1.0%
2025	6.8%	4.1%	2.0%	48.0%	1.1%
2026	6.8%	4.1%	2.0%	53.2%	1.2%
2027	6.8%	4.1%	2.0%	53.3%	1.2%
2028	6.8%	4.1%	2.0%	53.3%	1.2%
2029	6.8%	4.1%	2.0%	53.2%	1.2%
2030	6.8%	4.1%	2.0%	53.2%	1.2%
2031	6.8%	4.1%	2.0%	53.1%	1.2%
2032	6.8%	4.1%	2.0%	53.1%	1.2%
2033	6.8%	4.1%	2.0%	53.0%	1.2%
2034	6.8%	4.1%	2.0%	52.9%	1.2%
2035	6.8%	4.1%	2.0%	52.7%	1.2%
2036	6.8%	4.1%	2.0%	52.5%	1.2%
2037	6.8%	4.1%	2.0%	52.2%	1.2%
2038	6.8%	4.1%	2.0%	52.0%	1.2%
2039	6.8%	4.1%	2.0%	51.7%	1.2%
2040	6.8%	4.1%	2.0%	51.6%	1.2%
2041	6.8%	4.1%	2.0%	51.4%	1.2%
2042	6.8%	4.1%	2.0%	51.2%	1.2%
2043	6.8%	4.1%	2.0%	51.1%	1.2%
2044	6.8%	4.1%	2.0%	50.9%	1.2%
2045	6.8%	4.1%	2.0%	50.7%	1.2%
2046	6.8%	4.1%	2.0%	50.6%	1.2%

Table 18A.2.2 Annual Increases in Market Shares Attributable to Alternative Policy Measures for General Service Fluorescent Lamps (T5 MiniBP Standard Output)

Year	Consumer Rebates	Consumer Tax Credits	Manufacturer Tax Credits	Voluntary Energy Efficiency Targets	Bulk Government Purchases
2017	5.2%	3.1%	1.6%	3.7%	0.1%
2018	5.2%	3.1%	1.6%	6.3%	0.3%
2019	5.2%	3.1%	1.6%	8.1%	0.4%
2020	5.2%	3.1%	1.6%	9.0%	0.5%
2021	5.2%	3.1%	1.6%	9.6%	0.6%
2022	5.2%	3.1%	1.6%	10.4%	0.7%
2023	5.2%	3.1%	1.6%	11.5%	0.8%
2024	5.2%	3.1%	1.6%	12.8%	0.9%
2025	5.2%	3.1%	1.6%	14.2%	1.1%
2026	5.2%	3.1%	1.6%	15.5%	1.2%
2027	5.2%	3.1%	1.6%	15.2%	1.2%
2028	5.2%	3.1%	1.6%	15.0%	1.2%
2029	5.2%	3.1%	1.6%	14.8%	1.2%
2030	5.2%	3.1%	1.6%	14.7%	1.2%
2031	5.2%	3.1%	1.6%	14.6%	1.2%
2032	5.2%	3.1%	1.6%	14.5%	1.2%
2033	5.2%	3.1%	1.6%	14.4%	1.2%
2034	5.2%	3.1%	1.6%	14.2%	1.2%
2035	5.2%	3.1%	1.6%	14.0%	1.2%
2036	5.2%	3.1%	1.6%	13.8%	1.2%
2037	5.2%	3.1%	1.6%	13.6%	1.2%
2038	5.2%	3.1%	1.6%	13.4%	1.2%
2039	5.2%	3.1%	1.6%	13.2%	1.2%
2040	5.2%	3.1%	1.6%	13.1%	1.2%
2041	5.2%	3.1%	1.6%	13.0%	1.2%
2042	5.2%	3.1%	1.6%	12.9%	1.2%
2043	5.2%	3.1%	1.6%	12.7%	1.2%
2044	5.2%	3.1%	1.6%	12.6%	1.1%
2045	5.2%	3.1%	1.6%	12.5%	1.1%
2046	5.2%	3.1%	1.6%	12.4%	1.1%

18A.3 NIA-RIA INTEGRATED MODEL

For this analysis, DOE used its integrated NIA-RIA^a model approach that built on the NIA model discussed in Chapter 12 and documented in Appendix 12A. The resulting integrated NIA-RIA model featured both the NIA analysis inputs and the RIA inputs and had the capability to generate results for each of the RIA policies. A separate module produced results summaries for the tables and figures in the RIA document. For the RIA methodology documentation in Chapter 18, the module created summaries of parameters calculated by the model for the consumer rebates policy, generated its penetration curves (discussed in Section 18A.4.3 below), and reported market share impacts for the rebate and tax credit policies by lamp type. For the RIA results reported in Chapter 18, the module produced graphs of the market share increases resulting from each of the policies analyzed and created summary tables for the national energy savings (NES) and net present value (NPV) results. This module also generated tables of market share increases for each policy reported in Section 18A.2 of this Appendix.

18A.4 CONSUMER REBATE POLICY MARKET PENETRATION CURVES

This section first discusses the theoretical basis for the market penetration curves that DOE used to analyze the Consumer Rebates policy. Next it discusses the adjustments it made to the maximum penetration rates. It then refers to the method it used to develop interpolated penetration curves for each specific lamp type and efficiency level in the analysis. The resulting curves for GSFL lamp types are in Chapter 18.

18A.4.1 Introduction

XENERGY, Inc.^b, developed a re-parameterized, mixed-source information diffusion model to estimate market impacts induced by financial incentives for purchasing energy efficient appliances.¹ The basic premise of the mixed-source model is that information diffusion drives the adoption of technology.

Extensive economic literature describes the diffusion of new products as technologies evolve. Some research focuses primarily on developing analytical models of diffusion patterns applicable to individual consumers or to technologies from competing firms.^{2, 3, 4} One study records researchers' attempts to investigate the factors that drive diffusion processes.⁵ Because a new product generally has its own distinct characteristics, few studies have been able to conclusively develop a universally applicable model. Some key findings, however, generally are accepted in academia and industry.

One accepted finding is that, regardless of their economic benefits and technological merits, new technologies are unlikely to be adopted by all potential users. For many products, a ceiling must be placed on the adoption rate. A second conclusion is that not all adopters purchase new products at the same time: some act quickly after a new product is introduced; others wait

^a NIA = national impact analysis; RIA = regulatory impact analysis

^b XENERGY is now owned by KEMA, Inc. (www.kema.com)

for the product to mature. Third, diffusion processes can be characterized approximately by asymmetric S-curves that depict three stages of diffusion: starting, accelerating, and decreasing (as the adoption ceiling is approached).

A so-called epidemic model of diffusion is used widely in marketing and social studies. The epidemic model assumes that (1) all consumers place identical value on the benefits of a new product, and (2) the cost of a new product is constant or declines monotonically over time. What induces a consumer to purchase a new product is information about the availability and benefits of the product. In other words, information diffusion drives consumers' adoption of a new product.³ The model incorporates information diffusion from both internal sources (spread by word of mouth from early adopters to prospective adopters) and external sources (the "announcement effect" produced by government agencies, institutions, or commercial advertising). The model incorporates both internal and external sources by combining a logistic function with an exponential function.^{4,5}

The relative degree of influence from the internal and external sources determines the general shape of the diffusion curve for a specific product.^{4,5} If adoption of a product is influenced primarily by external sources of information (the announcement effect), for instance, a high rate of diffusion occurs at the beginning of the process. In this scenario, external sources provide immediate information exposure to a significant number of prospective adopters. In contrast, internal sources (such as a network of prospective adopters) are relatively small in size and reach, producing a more gradual exposure to prospective adopters. Graphically speaking, information diffusion dominated by external sources is represented by a concave curve (the exponential curve in Figure 18A.4.1). If adoption of a new product is influenced most strongly by internal sources of information, the number of adopters increases gradually, forming a convex curve (the logistic curve in Figure 18A.4.1).

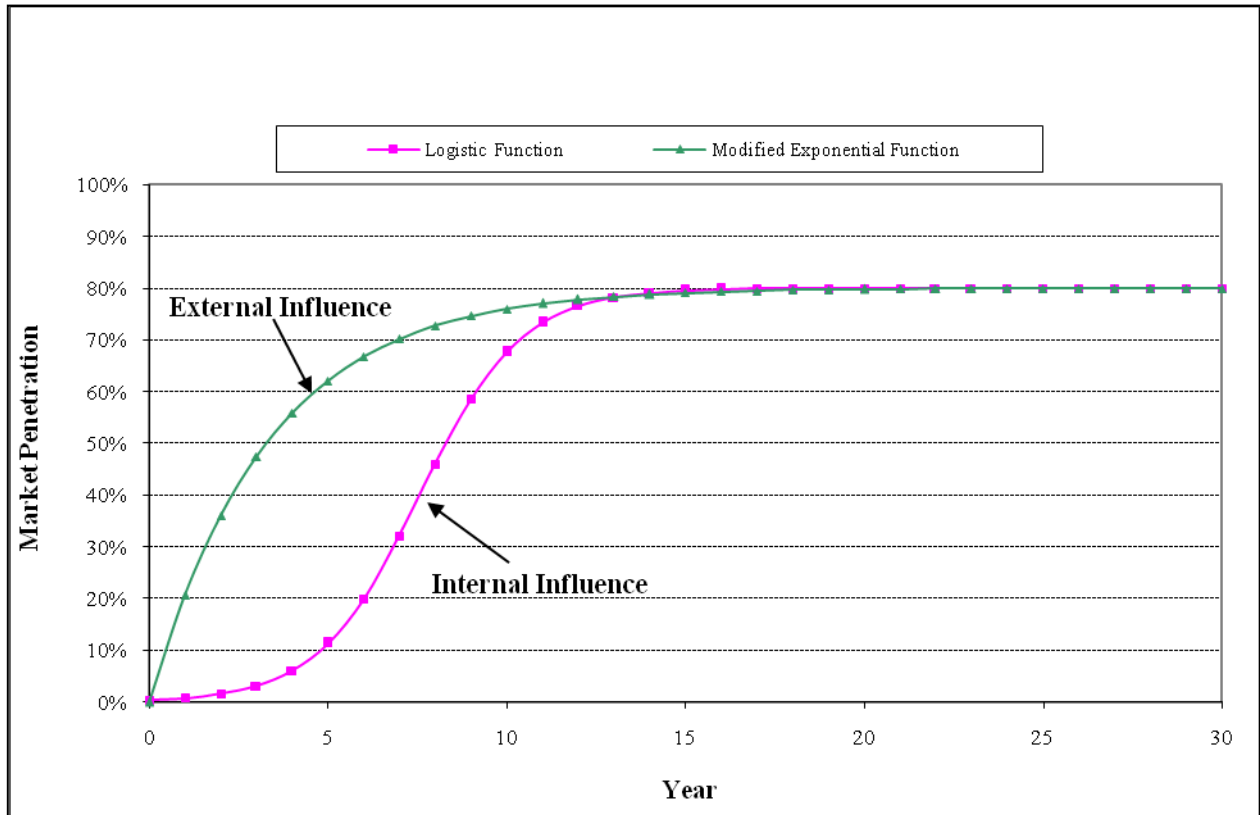


Figure 18A.4.1 S-Curves Showing Effects of External and Internal Sources on Adoption of New Technologies

18A.4.2 Adjustment of XENERGY Penetration Curves

In consultation with the primary authors of the 2002 XENERGY study who later conducted similar California studies, DOE made some adjustments to XENERGY's original implementation (penetration) curves.⁶ The experiences with utility programs since the XENERGY study indicate that incentive programs have difficulty achieving penetration rates as high as 80 percent. Consumer response is limited by barriers created by consumer utility issues and other non-economic factors. DOE therefore adjusted the maximum penetration parameters for some of the curves from 80 percent to the following levels:

Moderate Barriers:	70%
High Barriers:	60%
Extremely High Barriers:	50%

The *low barriers* and *no barriers* curves (the latter used only when a product has a very high base-case-market share) remained, respectively, with 80 percent and 100 percent as their maximum penetration rates. For the interpolated penetration curves (discussed below), DOE set the *no barriers* and *extremely high barriers* curves as the upper and lower bounds, respectively, for any benefit/cost ratio points higher or lower than the curves. It set another constraint such

that the policy case market share cannot be great than 100 percent, as might occur for products with high base case market shares of the target-level technology.

18A.4.3 Interpolation of Penetration Curves

As discussed above, the XENERGY penetration (implementation) curves followed a functional form to estimate the market implementation rate caused by energy efficiency measures such as consumer rebates.^c The XENERGY report presents five reference market implementation curves that vary according to the level of market barriers to technology penetration.¹ Such curves have been used by DOE in the Regulatory Impact Analyses for rulemakings for appliance energy efficiency standards to estimate market share increases in response to rebate programs.^d They provide a framework for evaluating technology penetration, yet require matching the studied market to the curve that best represents it. This approximate matching can introduce some inaccuracy to the analysis.

Blum et al (2011, Appendix A)⁷ presents an alternative approach to such evaluation: a method to estimate market implementation rates more accurately by performing interpolations of the reference curves. The referred report describes the market implementation rate function and the reference curves, the method to calibrate the function to a given market, and the limitations of the method.

^c The RIA chapter refers to these curves as *penetration curves*. This section, in references to the original source, uses the term *implementation curve*.

^d DOE has also used this method to estimate market share increases resulting from consumer tax credit and manufacturer tax credit programs, since the effects of tax credits on markets can be considered proportional to the rebate impacts.

18A.5 CONSUMER REBATE PROGRAMS

DOE performed a search for rebate programs that offered incentives for GSFLs. Some organizations nationwide, comprising electric utilities and regional agencies, offer rebate programs for these lamps. Table 18A.5.3 provides the organizations' names, states, targeted lamps, rebate amounts, and program websites. If there is more than one entry for an organization, it offers different rebates in different states. When an organization offers rebates through several utilities, it is represented only once in each table.

DOE performed statistical analysis to calculate what a typical rebate amount for T8 4-ft Medium Bipin lamps and T5 MiniBP Standard Output lamps would be. It relied on the data it gathered from 30 rebates programs offered by 19 organizations as reported on Table 18A.5.3. DOE used the information from those programs to estimate a rebate value for each type of lamp using the following regression model:

$$reb(len, type) = \beta_{len} \cdot len + \beta_{type} \cdot type + \varepsilon$$

where:

$reb(len, type)$	rebate value offered towards a lamp with length len and type $type$
len	variable indicating the length of the lamp
$type$	<i>dummy</i> variable indicating whether the rebate program targets a T5 lamp ($type = 1$) or not ($type = 0$)
β_x	statistical coefficients
ε	statistical error.

Table 18A.5.1 shows the results for the model above. Table 18A.5.2 presents the rebate amounts calculated upon these results for each type of lamp covered by this RIA class.

Table 18A.5.1 Results from regression model*

	Coefficient	Unit	SE	P-Value
β_{len}	0.231	dollars/foot	0.014	0.000
β_{type}	-0.304	dollars	0.127	0.021

* $R^2=0.882$

Table 18A.5.2 Rebate amount by lamp type

Lamp Type	Length (feet)	Type	Rebate (2012\$)
T8 4-ft Medium Bipin	4	0	0.923
T5 MiniBP Standard Output	5	1	0.850

Table 18A.5.3 Rebates for General Service Fluorescent Lamps*

Organization	State	Lamp Type	Rebate (\$)	Website
San Diego Gas & Electric	CA	T8	1.00	http://www.sdge.com/rebates-finder/earn-rebates-your-improvements
San Diego Gas & Electric	CA	T8	0.50	http://www.sdge.com/rebates-finder/earn-rebates-your-improvements
Southern California Edison	CA	T8	0.50	https://www.sce.com/wps/portal/home/business/savings-incentives/express-solutions/eligibility
Southern California Edison	CA	T8	1.00	https://www.sce.com/wps/portal/home/business/savings-incentives/express-solutions/eligibility/
Xcel Energy (Colorado)	CO	T8	0.50	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Lighting_Efficiency_-_CO
Idaho Power	ID	T8	1.00	https://www.idahopower.com/EnergyEfficiency/Business/Programs/EasyUpgrades/default.cfm
Idaho Power	ID	T5	1.00	https://www.idahopower.com/EnergyEfficiency/Business/Programs/EasyUpgrades/default.cfm
Consumers Energy	MI	T8	0.75	http://www.consumersenergy.com/eeprograms/BHome.aspx?id=5435
DTE Energy	MI	T8	1.00	https://www2.dteenergy.com/wps/portal/dte/business/saveEnergy/details/incentives_and_offers/how_to_participate/
Southern Minnesota Municipal Power Agency	MN	T8	1.00	http://www.austinutilities.com/pages/businessRebatesLighting12.asp
Southern Minnesota Municipal Power Agency	MN	T8	1.50	http://www.austinutilities.com/pages/businessRebatesLighting12.asp
Xcel Energy (Minnesota)	MN	T8	0.50	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Lighting_Efficiency_-_MN
Nebraska Public Power District	NE	T8	1.00	http://www.nppd.com/save-energy/for-your-business/
Nebraska Public Power District	NE	T8	2.00	http://www.nppd.com/save-energy/for-your-business/
Nebraska Public Power District	NE	T8	0.75	http://www.nppd.com/save-energy/for-your-business/
PNM Resources	NM	T8	0.50	http://www.pnmenergyefficiency.com/Projects/Default.aspx?tabid=909
Xcel Energy (New Mexico)	NM	T8	0.50	http://www.xcelenergy.com/Save_Money_&_Energy/For_Your_Business/Equipment_Efficiency/Lighting_Efficiency_-_NM
AEP Ohio	OH	T8	1.50	https://www.aepohio.com/save/programs/PrescriptiveProgram.aspx

Organization	State	Lamp Type	Rebate (\$)	Website
Idaho Power	OR	T8	1.00	https://www.idahopower.com/EnergyEfficiency/Business/Programs/EasyUpgrades/default.cfm
Idaho Power	OR	T5	1.00	https://www.idahopower.com/EnergyEfficiency/Business/Programs/EasyUpgrades/default.cfm
PECO	PA	T8	1.00	https://www.peco.com/Savings/ProgramsandRebates/Business/Pages/PECOSmartEquipmentIncentives.aspx
PPL Electric Utilities	PA	T8	1.00	https://www.pplelectric.com/save-energy-and-money/rebates-and-discounts/business-and-nonprofit/rebates/lighting.aspx
Rocky Mountain Power (Utah)	UT	T8	0.25	http://www.rockymountainpower.net/bus/se/utah/il/lighting.html
Rocky Mountain Power (Utah)	UT	T5	0.25	http://www.rockymountainpower.net/bus/se/utah/il/lighting.html
Puget Sound Energy	WA	T8	1.00	http://pse.com/savingsandenergycenter/ForBusinesses/Pages/Reduced-Wattage-T8-Lighting.aspx
Tacoma Power	WA	T8	1.00	http://www.mytpu.org/tacomapower/save-energy-money/save-in-your/lighting/
Focus on Energy (offered by 106 utilities)	WI	T8	1.00	http://www.focusonenergy.com/business/efficient-equipment/lighting
Focus on Energy (offered by 106 utilities)	WI	T5	1.00	http://www.focusonenergy.com/business/efficient-equipment/lighting
Rocky Mountain Power (Wyoming)	WY	T8	0.25	http://www.rockymountainpower.net/bus/se/wyoming/ilc/fe2/1.html
Rocky Mountain Power (Wyoming)	WY	T5	0.25	http://www.rockymountainpower.net/bus/se/wyoming/ilc/fe2/1.html

* T8 Medium Bipin; T5 MiniBP Standard Output

18A.6 FEDERAL AND STATE TAX CREDITS

This section summarizes the Federal and State tax credits available to consumers who purchase energy efficient appliances. This section also describes tax credits available to manufacturers who produce certain energy efficient appliances.

18A.6.1 Federal Tax Credits for Consumers

EPACT 2005 included Federal tax credits for consumers who installed efficient air conditioners or heat pumps; gas, oil and propane furnaces and boilers; furnace fans; and/or gas, oil, or electric heat pump water heaters in new or existing homes.^{8,9} These tax credits were in effect in 2006 and 2007, expired in 2008, and were reinstated for 2009–2010 by the American Recovery and Reinvestment Act (ARRA).¹⁰ There was a \$1,500 cap on the credit per home, including the amount received for insulation, windows, and air and duct sealing. Congress extended this provision for 2011, with some modifications to eligibility requirements, and reductions in the cap to \$500 per home. The American Taxpayer Relief Act of 2012 extended, with some modifications, residential tax credits for air conditioners, heat pumps, furnaces, and water heaters placed in service between January 1, 2012 and December 31, 2013.^{8,11} The tax credit for furnace fans was \$50 in 2011, after which it expired.

The importance of the Federal tax credits has been emphasized in research in the residential heating industry on the impacts of the relatively large credits that were available for HVAC (heating, ventilating, and air conditioning) equipment. In a survey of HVAC distributors conducted by Vermont Energy Investment Corporation, respondents indicated that the ample credit had had a notable impact on sales of higher-efficiency heating and cooling equipment. Some distributors combined the Federal tax credits with manufacturer rebates and utility program rebates for a greater consumer incentive. However, when the amount of the Federal tax credit was reduced, smaller utility rebate incentives had not induced the same levels of equipment sales increases. The decrease in incentive size from a \$1,500 cap in 2009–2010 to a \$500 cap in 2011, during a period when the economy continued to be sluggish, resulted in a decline in total sales of residential HVAC products. Distributors stated that an incentive needed to cover 25 to 75 percent of the incremental cost of the efficient equipment to influence consumer choice. The industry publication “2011 HVAC Review and Outlook” noted a decline in sales of air conditioning units with >14 SEER in 2011 and a return in sales of units with >16 SEER to 2009 levels (after an increase in 2010). The large majority of distributor observed no impacts from the utility programs with their lower rebate amounts available in 2011. Distributors also commented on the advantages of the Federal tax credit being nationwide in contrast to utility rebate programs that target regional markets.^{12,13}

In an effort to evaluate the potential impact of a Federal appliance tax credit program, DOE reviewed Internal Revenue Service (IRS) data on the numbers of taxpayers who claimed the tax credits during tax years 2006 and 2007. It estimated the percentage of taxpayers who filed Form 5695, *Residential Energy Credits*.¹⁴ It also estimated the percentage of taxpayers with entries under Form 5695’s section 3, *Residential energy property costs*, line 3b, *qualified natural gas, propane, or oil furnace or hot water boiler*. DOE reasoned that the percentage of taxpayers

with an entry on Line 3b could serve as a rough indication of the potential of taxpayer participation in a Federal tax credit program for furnaces during the initial program years. DOE found that of all residential taxpayers filing tax returns, 0.8 percent in 2006 and 0.6 percent in 2007, claimed a credit for a furnace or boiler. DOE further found that the percentages of those filing Form 5695 for any qualifying energy property expenditure (which also included installation of efficient windows, doors and roofs) were 3.1 and 3.2 percent in 2006 and 2007 respectively.

DOE also reviewed data from an earlier Federal energy conservation tax credit program in place in the 1980s. While this tax credit was available from 1979 through 1985, DOE located data for only the first three years of the program.^{15, 16, 17} For those three years - 1979, 1980, and 1981 - the percentages of taxpayers filing Form 5695 were 6.4 percent, 5.2 percent, and 4.9 percent. Given that the data from this earlier tax credit program were not disaggregated by type of energy property, this data series served only to indicate a possible trend of greater participation in the initial program year, followed by slightly smaller participation in subsequent years. However, DOE did not find detailed analysis of this program to indicate the possible reasons for such a trend. Also, this trend varies from the more stable trend shown in the EPAct 2005 energy tax credit program data for its first two program years.

As discussed in Chapter 18, DOE analyzed the percentage of participation in consumer tax credit programs using its estimates of consumer participation in rebate programs that was based on benefit/cost data specific to each lamp type. Hence it was difficult to compare these detailed estimates to the more general data analysis described above from the existing Federal tax credit program, or to use the IRS data analysis in its consumer tax credit analysis.

18A.6.2 Federal Tax Credits for Manufacturers

EPACT 2005 provided Federal Energy Efficient Appliance Credits to manufacturers that produced high-efficiency refrigerators, clothes washers, and dishwashers in 2006 and 2007.¹⁸ The Emergency Economic Stabilization Act of 2008¹⁹ amended the credits and extended them through 2010. The credits were extended again to 2011 with modifications in the eligibility requirements. Manufacturer tax credits were extended again, by the American Taxpayer Relief Act of 2012, for clothes washers, refrigerators, and dishwashers manufactured between January 1, 2012 and December 31, 2013.²⁰

Manufacturers who produce these appliances receive the credits for increasing their production of qualifying appliances. These credits had several efficiency tiers in 2011. For 2012-2013, credits for the higher tiers remain but were eliminated for the lowest (least efficient) tiers for clothes washers and dishwashers.¹¹ The credit amounts applied to each unit manufactured. The credit to manufacturers of qualifying clothes washers, refrigerators and dishwashers was capped at \$75 million for the period of 2008-2010. However, the most efficient refrigerator (30%) and clothes washer (2.2 MEF/4.5 wcf) models was not subject to the cap. The credit to manufacturers was capped at \$25 million for 2011, with the most efficient refrigerators (35%) and clothes washers (2.8 MEF/3.5 WCF) exempted from this cap.²¹

18A.6.3 State Tax Credits

The States of Oregon and Montana have offered consumer tax credits for efficient appliances for several years, and the States of Kentucky, Michigan and Indiana began offering such credits in 2009. The Oregon Department of Energy (ODOE) has disaggregated data on taxpayer participation in credits for eligible products. (See the discussion in Chapter 18 on tax credit data for clothes washers.) Montana's Department of Revenue does not disaggregate participation data by appliance, although DOE reviewed Montana's overall participation trends and found them congruent with its analysis of Oregon's clothes washer tax credits.

Oregon's Residential Energy Tax Credit (RETC) was created in 1977. The Oregon legislature expanded the RETC program in 1997 to include residential refrigerators, clothes washers, and dishwashers, which significantly increased participation in the program. The program subsequently added credits for high-efficiency heat pump systems, air conditioners, and water heaters (2001); furnaces and boilers (2002); and duct/air sealing, fuel cells, heat recovery, and renewable energy equipment. Beginning in 2012 a Tax Credit Extension Bill (HB3672) eliminated refrigerators, clothes washers, dishwashers, air conditioners, and boilers from the RETC program, leaving credits for water heaters, furnaces, heat pumps, tankless water heaters, and heat pump water heaters.^{22, 23} Those technologies recognized by the Oregon Department of Energy as "premium efficiency" are eligible for tax credit of \$0.60 per kWh saved in the first year (up to \$1,500).^{22, 24}

Montana has had an Energy Conservation Tax Credit for residential measures since 1998.²⁵ The tax credit covers various residential energy and water efficient products, including split system central air conditioning; package system central air conditioning; split system air source heat pumps; package system heat pumps; natural gas, propane, or oil furnaces; hot water boilers; advanced main air circulating fans; heat recovery ventilators; gas, oil, or propane water heaters; electric heat pump water heaters; low-flow showerheads and faucets; light fixtures; and controls. In 2002 the amount of the credit was increased from 5 percent of product costs (up to \$150) to 25 percent (up to \$500) per taxpayer. The credit can be used for products installed in new construction or remodeling projects. The tax credit covers only that part of the cost and materials that exceed established standards of construction.

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