Steel production & environmental impact

Key points

- Steel is 'iron with most of the carbon removed'
- Iron constitutes about five per cent of the Earth's crust and is the fourth most abundant element in the crust.
- 98% of the iron ore mined is used to make steel
- Steel represents around 95% of all metals produced
- The biggest producer of steel by far is China (1607 million metric tonnes in 2013), followed by the EU (165), Japan (110), USA (87) and India (81)
- Steel use per capita increased from 150kg in 2001 to 220kg in 2010 (Wsteel Assoc)
- 51% of global steel is used for construction (Wsteel Assoc
- 6.5% of CO_2 emissions derive from iron and steel production (IEA 2010)

1 Mineral Extraction

Iron ore

- Iron doesn’t occur naturally. Being highly reactive, it combines easily with other minerals to form ores. Those with the highest iron content are found near the surface of the earth and are relatively easy to mine.
- The principal iron ores are hematite (Fe_2O_3) and magnetite (Fe_3O_4).
- Most iron ore is extracted through opencast mines.
- To be economically viable for mining, iron ore must contain at least 20% iron.
- The three major sources of iron are China (23%), Australia (18%) and Brazil (18%). (2011 figures)

Where to find it

Iron ore mining in Western Australia

Iron ore is converted into various types of iron through several processes. The most common process is the use of a blast furnace to produce pig iron which is about 92-94% iron and 3-5% carbon with smaller amounts of other elements. Pig iron has only limited uses, and most of this iron goes on to a steel mill where it is converted into various steel alloys by further reducing the carbon content and adding other elements such as manganese and nickel to give the steel specific properties.

Limestone

- Limestone is calcium carbonate ($CaCO_3$). It is mainly composed of the skeletal remains of marine organisms.
- Geologically, limestone occurs as a sedimentary layer over bedrock. As such it is relatively easy to extract through quarrying.
- Limestone is removed from the quarry, crushed and transported to steel mills.

Coke

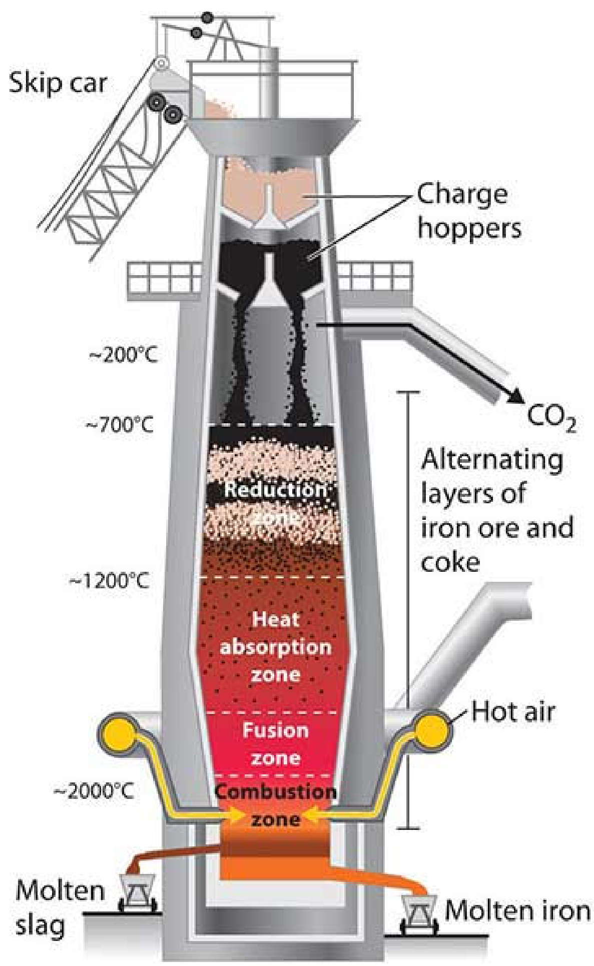
Coke is produced from coal. The coal is heated, or 'carbonised' in an oven until it becomes coke. It is then removed from the oven and cooled before use in the blast furnace. The coal gas produced during carbonisation is collected and used as a fuel in the manufacturing process while by-products such as tar, benzole and sulphur are extracted for further refining.

2 Manufacture of Iron

Pig Iron

Coke, ore and sinter are fed, or ‘charged’, into the top of the blast furnace, together with limestone. A hot air blast, from which the furnace gets its name, is injected through nozzles, called ‘tuyeres’, in the base of the furnace. The blast fans the heat in the furnace to white-hot intensity, and the iron in the ore and sinter is melted out to form a pool of molten metal in the bottom, or hearth, of the furnace. The limestone combines with impurities and molten rock from the iron ore and sinter, forming a liquid ‘slag' which, being lighter than the metal, floats on top of it.

- 2C (carbon(coke)) + 0_2 (oxygen) >>> 2CO (carbon monoxide)
- Fe_2O_3 (iron ore) + 3 CO (carbon monoxide) >>> 2Fe(iron) + 3 CO_2 (carbon dioxide)



(a) Blast furnace

(b) World's largest blast furnace in 1931

Cast Iron

The molten iron from the bottom of the furnace can be used as cast iron.

Cast iron is very runny when it is molten and doesn't shrink much when it solidifies. It is therefore ideal for making castings - hence its name. However, it is very impure, containing about 4% of carbon. This carbon makes it very hard, but also very brittle.

3 Manufacture of Steel

Methods for manufacturing steel have evolved significantly since industrial production began in the late 19th century. Modern methods, however, are still based around the Bessemer Process, namely, how to most efficiently use oxygen to lower the carbon content in iron.

Today, steel making comes from both recycled as well as from raw materials. Two processes:

- Basic Oxygen Steelmaking (BOS)/ Basic Oxygen Furnace (BOF) and
- Electric Arc Furnace (EAF) account for virtually all steel production.

Primary steel production

Primary steelmaking methods differ between BOS and EAF methods. BOS methods add recycled scrap steel to the molten iron in a converter. At high temperatures, oxygen is blown through the metal, lowering silicon, manganese and phosphorous levels and lowering carbon content to between 0-1.5%. The addition of chemical cleaning agents called fluxes help to reduce the sulfur and phosphorous levels.

EAF methods, alternatively, derive from 90 -100% recycled steel scrap and passed high power electric arcs (temperatures up to 1650 °C) to melt the metal and convert it to high quality steel.

Secondary steel production

Secondary steelmaking involves treating the molten steel produced from both BOS and EAF routes to adjust the steel composition. This is done by adding or removing certain elements and/or manipulating the temperature and production environment.

Continuous Casting

The molten steel is cast into a cooled mould causing a thin steel shell to solidify. The shell strand is withdrawn using guided rolls and fully cooled and solidified. The strand is cut into desired lengths depending on application; slabs for flat products (**plate and strip**), blooms for sections (**beams**), billets for long products (**wires**) or thin strips.

Primary Forming

The steel that is cast is then formed into various shapes, often by hot rolling, a process that eliminates cast defects and achieves the required shape and surface quality. Hot rolled products are divided into flat products, long products, seamless tubes, and specialty products.

Manufacturing, Fabrication and Finishing

Finally, secondary forming techniques give the steel its final shape and properties. These techniques include:

- shaping (e.g. cold rolling)
- machining (e.g. drilling)
- joining (e.g. welding)
- coating (e.g. galvanising)
- heat treatment (e.g. tempering)
- surface treatment (e.g. carburising)

4 Types of Steel

Carbon Steels

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorised into three groups depending on their carbon content:

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon

Alloy Steels

Alloy steels contain alloying elements (e.g. manganese, silicon, nickel, titanium, copper, chromium and aluminium) in varying proportions in order to manipulate the steel's properties, such as its hardenability, corrosion resistance, strength and ductility along with its abilities to be formed and welded

Stainless Steels

*stainless steel pipe*s

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. Stainless steels can be divided into three groups based on their crystalline structure:

• **Austenitic**: Austenitic steels generally contain 18% chromium, 8% nickel and less than 0.8% carbon. They form the largest portion of the global stainless steel market. Typical use of austenitic steel is in masonry support systems.

• **Ferritic**: Ferritic steels are weaker and less ductile than austenitic steels. They contain trace amounts of nickel, 12-17% chromium, less than 0.1% carbon. They are prone to 'pitting' so if appearance is important, their use tends to be limited to internal applications such as shop fitting.

• **Martensitic**: Martensitic steels are strong but brittle and harder to weld and shape. They contain 11-17% chromium, less than 0.4% nickel and up to 1.2% carbon. Though cheaper than austenitic steels, their low resistance to corrosion limits the range of suitable applications.

• **Duplex Steels**: Are a mixture of austentic and ferritic which makes them suitable for applications where corrosion resistance and strength are equally important .

5 Types of coating

- Zinc coated steel (galvanised)
- Aluminium-zinc alloy coated steel
- Organic coated: PVC plastisol
- Organic coated: Polyvinylidene difluoride (PVDF aka PVF2)
- Organic coated: Polyester
- Organic coating: Enamel

Galvanised steel sheet

6 Energy

- Total world crude steel production 2013: 1,606 Mt
- Average energy in the production of primary steel: 18.68 GJ/t
- Average CO_2 intensity: 1.77 t CO_2/t

Of which:

- Basic Oxygen Steelmaking (BOS): 70% of total production energy

- Electric Arc Furnace (EAF): 30% of total production energy

Electric Arc Furnace in operation

Energy sources in producing primary steel:

- 50% coking coal
- 35% electricity
- 5% natural gas
- 5% other gasses

(source World Steel Association)

7 Recycling & Reuse

Recycling

- 42% of crude steel produced is recycled material
- Re-melting proportion of steel scrap is constrained by availability. Availability can sometimes be defined as cost effective recovery.

Iron and steel are the world's most recycled materials, and among the easiest materials to reprocess, as they can be separated magnetically from the waste stream. Recycling is via a steelworks: scrap is either re-melted in an electric arc furnace (90-100% scrap), or used as part of the charge in a Basic Oxygen

Furnace (around 25% scrap). Any grade of steel can be recycled to top quality new metal, with no 'downgrading' from prime to lower quality materials as steel is recycled repeatedly.

Recovery and reuse in construction

Globally around 85% of construction steel is currently recovered from demolition (sourceWSA) (UK 96% source steelconstruction.info)

Re-use of structural steel

Steel reuse is any process where end-of-life steel is not re-melted but rather enters a new product use phase.

Steel buildings and products are intrinsically demountable. Easily re-usable components include:

- Piles (sheet and bearing piles)
- Structural members including hollow sections
- Light gauge products such as purlins and rails.

Reclaimed steel

Design for reuse

To facilitate greater reuse it is important that designers not only use steel but also do what they can to optimise future reuse. Steps that the designer can take to maximise the opportunity for reusing structural steel include:

- End plate beam to column and beam to beam connections
- Use bolted connections in preference to welded joints to allow the structure to be dismantled during deconstruction
- Use standard connection details including bolt sizes and the spacing of holes
- Ensure easy and permanent access to connections
- Where feasible, try to ensure that the steel is free from coatings or coverings that will prevent visual assessment of the condition of the steel.
- Minimise the use of fixings to structural steel elements that require welding, drilling holes, or fixing with Hilti nails; use clamped fittings where possible
- Identify the origin and properties of the component for example by bar-coding or e-tagging or stamping and keep an inventory of products
- Use long-span beams as they are more likely to allow flexibility of use and to be reusable by cutting the beam to a new length. (source: SteelConstruction.info)

8 The environmental impact of steel production

Steel production has a number of impacts on the environment, including air emissions (CO, SOx, NOx, PM2), wastewater contaminants, hazardous wastes, and solid wastes. The major environmental impacts from integrated steel mills are from coking and iron-making.

Climate change

Virtually all of the greenhouse gas emissions associated with steel production are from the carbon dioxide emissions related to energy consumption.

Emissions to air

Coke production is one of the major pollution sources from steel production. Air emissions such as coke oven gas, naphthalene, ammonium compounds, crude light oil, sulfur and coke dust are released from coke ovens.

Emissions to water

Water emissions come from the water used to cool coke after it has finished baking. Quenching water becomes contaminated with coke breezes and other compounds. While the volume of contaminated water can be great, quenching water is fairly easy to reuse. Most pollutants can be removed by filtration.

Waste

Slag, the limestone and iron ore impurities collected at the top of the molten iron, make up the largest portion of iron-making by-products. Sulfur dioxide and hydrogen sulfide are volatized and captured in air emissions control equipment and the residual slag is sold to the construction industry. While this is not a pollution prevention technique, the solid waste does not reach landfills.

Gaseous emissions and metal dust are the most prominent sources of waste from electric arc furnaces.