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RFI on Medium- and Heavy-Duty Electric Charging Technologies and Infrastructure Needs

Comments from the University of Delaware
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Note: Questions from the RFI are here answered in order; those not answered are ones for which we do not have particularly deep experience or expertise.

Category 1: Unique EV Charger and Station Needs

1). Market Evaluation: Please provide any information or plans that you have regarding the adoption of MHD EVs now and anticipated growth over time (by 2030 and 2040) by vehicle type (please refer to FHWA's vehicle classification definitions).

UD will purchase 10 to 20 EVs over the next decade, including Classes 2, 3, and 4. The UD EV R&D Group regularly consults with and advises UD Transportation services. Exelon has a fleet of 7,200 vehicles, and a commitment to electrify 50% of their fleets by 2030. These are predominantly Classes 2, 3, 6, and 5 (including bucket trucks) vehicles. Our UD group advises Delmarva Power and their parent company, Exelon regarding EVs and charging stations. We have also advised transit bus agency DART on demand charge reduction and TOU rate strategies for the charging schedule for their Class 4 transit buses with CCS chargers. We have diagnosed and advised regarding service for about 1,000 charging stations in the field, ~25 of which we exclusively maintain, for Class 4, 2, and 3 EVs. We have advised Class 4 and 8 OEMs on onboard and offboard charging systems for their EVs, in addition to many Class 2 OEMs. This comment draws on our design iterations and direct maintenance experience, these advising relationships, and our published analysis of utility fleets (see Metz & Kempton 2024 and Kempton, McGee and Ejzak 2024 in References).

2). Station Development Considerations: What factors should be considered for the siting, location and development of a MHD EV charging station? What features and site design elements need to be considered for a station designed to support MHD EVs deployed in the next five years considering both depot and en-route charging applications? How should grid interconnectivity/capacity be considered in the site design for MHD EV stations? Should certain site design elements be standardized (e.g., number of ports, physical dimensions/spacing between charging ports, pull-through charging bays, co-location with other fuels) or is flexibility needed to accommodate different MHD EV charging scenarios and site constraints?

While, class 2 and many class 3 EVs, depending on duty cycle, could be recharged with conventional passenger-car single-phase EVSE, it is insufficient as a generalized commercial solution. For legacy vehicles, CCS stations may be appropriate, but CCS1 is inadequate for both AC and DC charging in most medium and heavy-duty use cases.

SAE Universal EV socket-outlet AC power transfer (e.g. J3068 socket outlet, Kempton, McGee, and Ejzak 2024) can offer single-phase charging to NACS fleet passenger EVs up to 20kW while providing up to 52kW three-phase power transfer for larger vehicles from the same station. These Universal EVSEs can also be used to replace proprietary idle reduction systems for hybrid or ICE vehicles.

Class 4, 5, and 6 vehicles, and some class 3 vehicles, can use 3-phase AC with J3068 chargers (except those with more than 16-hour duty cycle). Class 7, 8, 9, and higher HVs would frequently need MCS (CharIN 2022) charging, although, depending on the duty cycle and maximum trip length, their needs may be met most days with 3-phase 480V with J3038 charging. To supply power for MCS EVSE, 480 VAC may be acceptable in some cases, but medium voltage is preferred (5kV to 30kV, typically 12.5kV), especially for multiple MCS EVSE at one site. These considerations affect site power planning and electrical service.

MCS can also be effectively deployed at lower power levels (CCS1 levels) to allow the industry to transition to a connector system that scales to high power levels. The transition to NACS/J3400 from CCS1 for passenger vehicles has eliminated the advantage of using CCS1 as a cross-class transitional charging system.

When appropriate, based on duty cycle and dwell time (e.g. MHD EVs parked overnight or at least parked for one shift), as detailed below, it is desirable to provide one low-cost AC station (at 20, 50 or 100 kW) for each fleet vehicle rather than more expensive DC stations (>100 kW) among which vehicles are rotated. This is lower cost (capital and maintenance cost), lower charging management effort, may provide site backup power, and makes it possible for grid services when not charging.

Overall EV socket-outlets for AC power transfer and MCS for DC power transfer cover the vast majority of use cases for medium and heavy-duty charging. Regarding standardization, for fleets, we feel it would be counterproductive to standardize the number of ports, spacing, or physical dimensions as part of a federal effort. These will be highly dependent on duty cycles, route length, cargo, and other specifics. There may be trade associations or consultants who provide guidelines for different types of industries and different duty cycles. For NEVI funding of public chargers, if such specifications are provided, they should be less restrictive than current NEVI requirements for passenger cars, for example having LIN-CP qualify as signaling for NEVI funding for MHD charging stations.

5). Community Engagement: What are best practices for engaging communities for the deployment of charging infrastructure for MHD EVs? What community needs should be accounted for when siting a location for a MHD EV charging station?

We are not experts on best practices for community engagement for MHD. Also, see 16.

8). Overnight Parking/Charging Needs: What is the anticipated need for overnight or long-duration parking for MHD EVs over the next 3 to 5 years and/or longer-term? Should these spaces be dedicated for electric MHD vehicles that are actively charging? Should these spaces also be made available for electric MHD trucks that are not actively charging or non-electric MHD vehicles?

Socket outlets allow for a high percentage of parking spots to be electrified while minimizing the exposed infrastructure which is both an obstacle to drivers and vulnerable to damage when not in use or when the spot is utilized by an ICE vehicle.

LIN-CP (SAE J3068/1) provides a low-cost low-complexity way to know which vehicle is plugged into what station, and what the SoC and other valuable data are. Additionally, it can identify the cause of faults with charging, leading to increased reliability.

The utility fleets we are familiar with drive during working hours and park overnight. Their EVs are parked in a row of EV spaces. The utility and university fleets have EVs with combinations of J1772, J3068 (type 2), and J3400-AC inlets. The EVs park at the matched charging station, but not at the same parking space within the type (e.g. one charging connector per parking space). DC charging stations are much higher cost so, yes they may be reserved for vehicles that are actively charging. AC stations are much lower cost, e.g. $500 for a 9.6 kW, or $4,000 for a 50-100 amp J3068 station. A 50 kW AC charger at $4,000 is a fraction of the cost of a DC fast charger. V2G-enabled AC chargers are suitable for providing and being compensated for grid services like frequency regulation and spinning reserves. Therefore in most cases for AC stations, it will not make sense to require EVs to move after completing charging. Use for facility storage or V2G sales may also motivate leaving EVs plugged in. Nevertheless, it may make sense to prohibit parking by non-EVs and EVs that are not plugged in.

Specific vehicles, e.g. bucket trucks, occasionally (once every 1-2 years) have to drive long distances when utilities cooperatively help each other with people and equipment to repair wide-scale line outages due to extreme weather. For these occasions, en-route MCS or possibly J3400-DC or legacy CCS would be needed.

As a second case, we have also worked with the Delaware Authority for Regional Transit (DART) bus fleet which had installed eight 60kW CCS (Combined Charging System) chargers for eight Proterra electric transit buses. Most stopped in the terminal around mid-day, four of which recharged ~2 hours although they could drive 7 hours on an overnight charge, so those mid-day top-ups did not appear to be needed. Because 3-4 buses were typically charging at overlapping times late each day (after end-of-day routes) the demand charges were extremely high (adding ~$3,500 per month. The site manager assigned a late-night worker to sequentially switch buses on and off chargers (later switching became essential as several DC chargers failed). Manual switching was both inefficient in labor costs and precluded doing any grid services because buses were charging at full power until 100% charged by 12 midnight - 2 am (analysis by Luke Hutchinson). For the whole fleet, there was only 1 mid-day recharge cycle less than 2 hours, so a dedicated 30 kW charger (like a low-cost 3-phase 480V AC) would have served all routes the majority of days, plus one 60-100 kW charger for special circumstances. This would have reduced station cost by up to 90% ($40K -> $4K) and also would have automatically reduced the demand charge by at least half, even without any active management.

Drawing from all these experiences, we would advocate the following:

- For Class 3: dedicated space and charger at 10 - 20 kW, SAE Universal AC socket-outlet or SAE J3400 AC, vehicle plugged in overnight.
- For Class 3 and 4 requiring faster charge: dedicated space, three-phase running 480V at 40 - 80 kW SAE J3068 (type 2) or SAE Universal AC socket-outlet (≤52kW).
- For Class 5 bucket trucks, class 4 buses, or other MHVs with a typical <60 mi/day but occasional long trips: dedicated space, 3-phase J3068 at 40-80 kW, vehicle supplied with additional MCS inlet for recharge during long trips.

These recommendations minimize the cost of charging equipment and obviate the need for labor to swap vehicles. The 40-80 kW power can be supplied economically with 3-phase J3068. Additionally, during long dwell parking (most overnights and non-work days), after charging is sufficient for the next day's driving, the vehicle can perform grid services.

Fleet electric MHD vehicles should have dedicated spaces for charging overnight and these spaces should not normally be made available for non-charging vehicles (non-charging in this context means any vehicle, EV or otherwise, not using the charging station). Grid services value and thus revenue, are approximately proportional to time plugged in, proper charger use could pay off the cost of a V2G-capable AC charging station quickly, often in less than a year (Metz & Kempton 2024).

10). Demand Response and Managed Charging: What demand response or managed charging strategies are needed and/or have been employed successfully for MHD charging locations?

Our EV R&D Group has designed and developed, and Nuvve has commercialized, charging stations that do controlled charging in response to either time of day or grid events (e.g. charging at low TOD rates or ceasing charging at high grid use times controlled by a utility or RTO request). These have been deployed by UD in Delaware, by Delmarva Power with UD, and by Nuvve at multiple locations from New York to California, for many Class 4 electric buses, as well as Classes, 5, 3, and 2 EVs. Many other commercial charging stations have some form of time-managed charging capability. Because electric vehicles doing unmanaged charging may substantially increase both total kWh and peak kW, they can substantially increase the site/facility electric bill, one example being our answer to 8. This can be mitigated by managed charging. The UD/Nuvve charging stations can also go beyond managed charging as they are capable of bidirectional power flow, see the next two responses.

11). Role of Onsite Energy Storage and Generation: What role is on-site energy storage and generation playing or could play in supporting MHD EV charging needs? What actions are needed to enable the utilization of cost-effective energy storage and generation?

Demand charges and on-peak charging can be a significant bill cost added on to the energy (kWh) cost. Theoretically, onsite energy storage could allow for a levelized use of energy and availability across the site. Our examination of purpose-built storage to support charging suggests this is a very expensive solution. In the cases we have analyzed, a more economical approach is managed charging, or the use of existing fleet vehicles in V2G mode to level charging of the entire fleet. Managed charging to reduce demand charge is also provided by Emporia, which can limit charging to not exceed a set maximum site power. Managed charging plus injection, as provided by Nuvve and other aggregators, substantially increases the savings or financial value–these alternatives have been analyzed and quantified (Metz and Kempton 2024).

12). Grid Interaction: What scenarios or use cases would be ideal for exporting power from charging sites back to the grid? What actions are needed to enable cost-effective exportable power?

Power export (known by utilities as injection) does not make sense for the case of en-route charging, which usually prioritizes the fastest energy transfer allowed by the equipment. The remainder of this response addresses the common case of MHD vehicles which have use cases involving overnight or other dwell times longer than the time required for sufficient energy transfer to the vehicle battery.

A simple use case is to export power under the control of a single fleet site, this is typically rewarded by a reduction in TOU rates or demand charge. As quantified in the table below, power export for TOU rates can provide facility bill savings 10x that of managed charging.

The aggregation of MHD vehicles to collectively export power back to the grid has the highest financial value to the vehicle or fleet owner and the highest benefit to the electric system. Many small storage units (individual EVs) are aggregated, making the aggregate's power capacity and reliability much higher than that of any one storage unit. The control principle at the aggregation level is that when any EV plugs into a registered charging station as part of an aggregation within one jurisdiction the EV and station jointly become a grid resource. The EV reports to the aggregator its unique identifier, stored energy, power capacity, and optionally its anticipated driving schedule. The charging station reports its grid location, capacity, and permissions at that location. From these, the aggregator can determine the power capacity and duration available. The station is the registered entity with the utility or RTO, and the dispatched resource is the EV-station pair. The aggregator then dispatches groups of resources to provide power to, or absorb power from, the grid, provide reactive power, etc. The aggregator's EV dispatch prioritizes driving needs over grid dispatch, which reliably provides sufficient energy for each individual's trips, yet in aggregate reliably provides grid needs.

We have helped set up or are familiar with multiple cases of aggregation of fleets of vehicles from Class 2 through Class 5, to provide and be paid for valuable grid services, most still running successful market operations. We are most familiar with 3 EV aggregation companies, running in several US states as well as Denmark and the Netherlands. The aggregator typically also assists the fleet or vehicle owner in achieving any regulatory requirements for power injection, qualification for the most valuable markets, and ensuring that driving needs are prioritized over bill savings.

Enabling actions needed from MHD OEMS are to include bidirectional on-board chargers, and for AC V2G, to implement LIN-CP signaling as specified in J3068 and J3400.

Regulatorily, state regulatory aspects are implemented in some states, but the nationwide implementation of V2G would benefit from more widespread implementation of the existing model states' regulations (as itemized in Metz and Kempton 2024 and described briefly here in 24). Implementation of needed rules and market access by RTOs is already in process, as required by FERC Order 2222.

15). Fleet Lessons Learned: For fleets experienced in operating and charging MHD EVs, what are some important lessons learned that should be incorporated in the buildout of national infrastructure to support charging activities?

Fleet vehicles with typical off-duty dwell times can significantly reduce electric bills, or earn revenue, from enabling export, either under site fleet operator control or via control by an aggregator.

Most charging needs can be met by low-cost AC charging at 20 - 60 kW (with J3400-AC up to 40 kW or J3068 up to 100 kW). These stations substantially reduce station capital and maintenance costs, and, with LIN-CP, are ready for site power management and/or grid services.

For uses such as Class 8 through 12 interstate travel, plus use of normally local vehicles in unusual conditions (e.g. a transit bus going to a distant shop for repair, or utility bucket trucks traveling to another utility for post-storm power restoration), an additional inlet for MCS will be needed on the vehicle and corresponding MCS charging on en-route stops along such routes.

16). Equity: What equity-related challenges or benefits could be associated with MHD EV charging? What strategies could increase those benefits or mitigate those challenges? Are there considerations important to independent owner operators and small fleets?

Small urban businesses using MD EVs can reduce the cost of their business site recharging by using the new UD AC charging standards. Importantly, these provide sufficient power for MD and for local routes, with much lower downtime and lower maintenance costs over time (and after the subsidies are gone).

Similarly, businesses with delivery vehicles can provide universal EV outlets for their trucks, and the same EV outlet can also be used for drivers or other employee's personal EVs to charge during the day while trucks are out (Kempton, McGee & Ejzak 2024), making EVs practical for a wider range of workers and urban residents.

An equity challenge is that currently, MHD EVs are more expensive to purchase than fuel vehicles, making it more difficult for small and minority-owned businesses to purchase. We believe this will be solved over time on the vehicle side, but in the short term, our recommendation for low-cost charging solutions helps by reducing the station cost side of the equation.

Category 2: Vehicle Charging Patterns

17). Minimum Power Requirements: Is there a preferred minimum power level (including any specific voltage or current requirements), both per charging port and per charging station, to adequately serve MHD EV needs in public locations now? In 5 years? In 10 years? Is there a minimum number of MHD charging ports at a charging station that would make it useful as an MHD charging site? Are there alternative performance-based requirements that should be considered for the provision of a minimum number of MHD charging ports or total power available?

We assume this question refers to en-route charging, as we are not familiar with public parking locations used by Class 4 and up vehicles. For en-route public charging of Class 2- 4 vehicles, J3068 at 3-phase 60 - 100 kW may be satisfactory, as well as J3400-DC. For Class 5 and up vehicles, MCS would likely be required. These would meet requirements for the indefinite future. We feel it would be counterproductive for guidelines or funding requirements to specify a minimum number of MHD ports per station. We feel it would be preferable to label charging stations with the power rather than to require certain levels per port.

For EV chargers in North America, there are three types of EV chargers in use, Type 1 SAE J1772, Type 2 SAE J3068, and Type 5 SAE J3400 (otherwise known as Tesla's standard charger). Type 1 chargers are the most common charger type currently used in North America, but of the three mentioned has the lowest average AC charge rate. Type 2 is used for higher-power AC charging (often around 50 kW 3 phase, with up to 100 kW allowed) and is cost-effective for servicing medium to heavy-duty vehicles in addition to light vehicles.

No EV charger type mentioned can be used interchangeably with each other, meaning as EV charging infrastructure grows some EVs will be excluded from some charging areas for the fact they do not have the correct port system. While adapters exist that allow EVs with different ports to charge with other connector types, adapters can lead to more faults, and having the correct adaptors on hand is more complex. SAE J3068 defines a universal outlet for modern charging stations. Such stations do not have a fixed charging cable, instead they have an outlet. The user or EV carries a charging cable matched to the port on their EV which can be plugged into any universal outlet. This means any EV can plug into that station, in addition, the removal of fixed charging hoses would cut down on the instances of damaged connectors and inlets. A medium-duty truck or bus, with say 100 kWh storage, could be charged from empty to near full in around 2 hours with a 50 kW charger. Charging on a typical day would be a fraction of the full charge.

Category 3: MHD EV Charger Technology and Standardization

21). Megawatt Charging Standard: What is the anticipated adoption timeline for megawatt charging system (MCS), and other proprietary and nonproprietary connectors, on charging infrastructure in various MHD segments and is there a preferred connector standard? Is it preferable to have multiple connector types at MHD public charging locations or a single type?

The passenger car industry is transitioning away from the CCS1 connector. This allows MHD to adopt a DC connector that covers a wide range of DC charging. CharIN (2022) recommends MCS function down to 500V so that 800V pack systems can utilize MCS at lower power levels.

Manufacturers such as Amphenol have indicated that they can produce MCS connectors at a comparable cost to CCS connectors at the same power level. Those types of compact MCS connectors and inlets could go into production next year (2025).

We do not have a clear timeline for the communication controllers required to implement MCS but pre-production systems are currently being tested.

22). MHD EV Controllers and Management System Considerations: How are EV charge controllers and battery management systems different in MHD EVs than in light-duty passenger EVs? How do charge controllers differ in EV chargers designed for MHD EVs compared to chargers designed for light duty passenger EV applications?

There are no fundamental differences of principle between light-duty and MHD on-board battery management, nor of charging stations. The power levels are of course different, leading to the differences in recommended connectors as discussed above.

24). Alternative Charging Technology Solutions: Are there additional standards or technologies, such as inductive charging or bi-directional charging, that should be considered? If so, please provide information about these technologies, their benefits, and their anticipated industry adoption timeframes.

We do not expect inductive charging to make sense for MHD vehicles, due to energy loss in inductive versus conductive power transfer, and due to the need for precise positioning of the vehicle in current inductive vehicle systems.

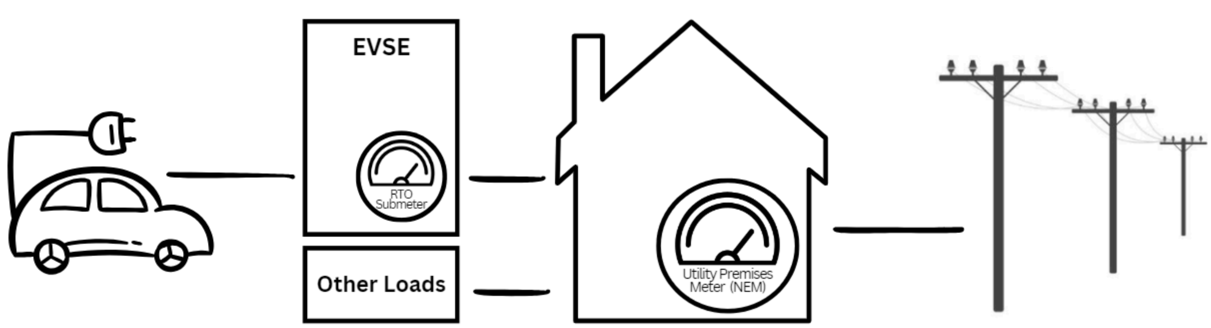
Based on market projections, EVs will become a huge electric storage resource over the next two decades. EV power capacity, if all EVs were charging or discharging simultaneously, would exceed the entire load of their respective RTOs. Given aggregate driving and charging patterns, they do not all charge at the same time, but this comparison illustrates the potential resource of EVs for storage. This form of storage is also very low cost because the battery and electronics are all already purchased for transport of the individual user or fleet, and they can provide controlled charging (demand management) or bidirectional power flow when they are not driving. The table below and our DART transit bus example show these are highly cost-effective for the fleet or vehicle owner. Therefore, we discuss the requirements for these capabilities.

Interconnection with injection needs to be approved by the utility, even for RTO markets. The interconnection standard for AC charging is SAE J3072 (the underlying standard is IEEE1547), some state rules or utilities already allow interconnection via IEEE1547 and J3072. Other states are waiting for UL1741-SC, in 1-2 years. If the grid service relies on a submeter for the EV behind-the-meter, the charging station is submetered (typically in kW), and the utility service meter can be a standard TOU or net energy meter. Storage is a net load as it cannot generate electricity. The utility can use conventional equipment for net energy metering at the premises. The aggregator, DER installer, or customer installs a submeter on the DER. In order for EVs to provide grid services, there needs to be an understanding among the RTOs, utilities, and states on metering requirements per market. Here is a list of metering solutions for EVs, specific to each of 3 markets for EVs:

- EVs provide storage for RTO ancillary services-only market, not participating in an utility market: utility premises have a net meter that measures energy. An RTO submeter sends data from the aggregator to the RTO (power and time in seconds).
- Storage to help the utility with time-of-use balancing: The utility meter is net, per time-of-use block. The PUC and utility adjust the on-peak versus off-peak cents/kWh to achieve the desired time shift. A submeter is not needed.
- Storage to provide utility with reactive power compensation: A standard utility premises meter measuring kWh is required with a submeter that measures real-time reactive power, with the aggregator sending data to the utility.

The meter topology and regulatory pathway are explained more fully in Metz and Kempton 2024 and in UD's regulatory filing in Pennsylvania, and ongoing discussions with the states of MD and DE (PA PSC 2024).

Below is a figure showing the bidirectional flow in an RTO ancillary services-only market with utility net metering, including a submeter reading power and premises meter reading energy. This is the only metering that is required to provide these services:



The revenue for earnings is shown in the table below from (Metz & Kempton 2024), with a brief summary of regulatory requirements.

Service	Net Meter Required	Interconnection Needed	How Grid Response Is Triggered	Regulatory Requirements	Revenue or Savings (USD/Year) by Charging Power		Simple Payback for 10 kW, Serial Production V2G
					10 kW	50 kW	
Backup power	No	No	Locally sense blackout	Transfer switch listed	n.a.		n.a.
Off-peak charging	No	No	Timed charging	TOU rate	USD 89	USD 89	6 years
Arbitrage with injection	Yes	Yes	Timed charging and discharging	TOU and NEM provided for retail storage	USD 650	USD 888	9 months
RTO regulation with injection	Yes	Yes	Signal from RTO via aggregator	Aggregation and market access (now required by FERC 2222)	USD 1455	USD 7510	4 months

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Category 4: Workforce, Supply Chain, and Manufacturing

29). High Power Charger Availability for MHD EVs: What is the expected commercial availability (both timing and volume) of the MCS or other proprietary connectors, cable assemblies, EV chargers, and adaptors? What safety standards will these products be certified against? Please provide any specifics on vehicle class, vocation, expected charging port type, pricing, and timing.

As noted above, MCS connectors are expected to be available in 2025. We expect MCS to meet UL 2202 because the scope of the document covers up to 1500 V DC.

Stations with J3068 connectors and Universal EV Outlet, and stations signaling with LIN-CP are available now, with more under development. Many MHD vehicles are now being developed with J3068 connectors and LIN-CP signaling.

References

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