2023 TECHNICAL UPDATE

Industry Perspectives on High-Power Charging from Electric Vehicle Supply Equipment (EVSE) Companies

Electric Truck Research and Utilization Center (eTRUC) Project (Task 3.3)

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ABSTRACT

The Electric Truck Research and Utilization Center (eTRUC) seeks to accelerate the commercial adoption of a high-power combined charging system (CCS) and megawatt-level technologies in medium- and heavy-duty drayage trucks.

The goal of eTRUC project Task 3.3 is to assess the maturity of charging infrastructure for high-power charging capable of adding at least 100 miles of range every 10 minutes. As part of task 3.3, a series of interviews with leading electric vehicle supply equipment (EVSE) manufacturers was performed to understand the current charging capabilities and the expected path to megawatt charging.

EVSE companies provided detailed insights on the 1) limits of today's EVSE supporting the Combined Charging System (CCS) standard (SAE J1772) for heavy-duty trucking and 2) developments for EVSE utilizing the Megawatt Charging System (MCS) standard. Perspectives included design considerations for MCS charging plazas, maintenance requirements, and expected cost differences compared to CCS. Alternative megawatt charging systems such as pantograph, pin and sleeve, and wireless were discussed. Comments were also made on the technology, grid, and business case readiness for megawatt charging.

Keywords

Heavy-duty drayage trucks
eTRUC
Charging infrastructure
Battery electric vehicles
Megawatt charging
EVSE

ACRONYM/TERM LIST

Acronym/Term	Meaning
A	Amps
AC	Alternating Current
CCS	Combined Charging System
CEC	California Energy Commission
CharIN	A global association involved in development of charging standards
DC	Direct Current
DCFC	Direct Current Fast Charger
DER	Distributed Energy Resources
EVSE	Electric Vehicle Supply Equipment
kW	Kilowatt
LV	Low Voltage (typically up to 600V)
MCS	Megawatt Charging System
MV	Medium Voltage (typically between 1000 and 35000 volts)
MW	Megawatt
SiC	Silicon Carbide based power electronics
V	Volts
VAC	Alternating current voltage
VDC	Direct current voltage
V2G	Vehicle-to-grid (electrical power specifically from vehicle to the grid)
VGI	Vehicle-grid-integration (bidirectional electrical power flow)

EXECUTIVE SUMMARY

An objective of the eTRUC program is to understand industry perspectives on the readiness for megawatt-scale charging for electric trucks and buses. Between February and May 2023, interviews were carried out with nine electric vehicle supply equipment (EVSE) companies that are active in the manufacturing of high-power direct current, fast charge (DCFC) products today.

The focus of the interviews was to understand the current status and limits of today's DCFC equipment, typically based on the Combined Charging System (CCS) standard (SAE J1772), and the expected transition to megawatt scale charging. Of particular interest was the planning and readiness to meet the CEC goal of adding 100 miles of range every 10 minutes, which equates to around 1.5 MW for a heavy-duty (HD) truck. Key perspectives from the interviews included:

- It was noted that CCS has a current limit of 500 A which may extend to 700+ A in the future. Theoretically, this current can be supplied at a maximum voltage of around 950 VDC, which implies a charging power limit from 500 kW to 700 kW.
- The industry does expect that HD trucks will need higher power (megawatt) charging. There is a new megawatt charging system (MCS) standard (SAE J3271) being considered across the industry. Although, other High-power charging systems are being considered, especially those designed to support automated charging, which would easily be used by the operator without the need to wrestle a heavy cable.
- Megawatt charging equipment based on MCS will start to be demonstrated in the next couple of years, with full production systems expected to be available around 2027.
- Three levels of MCS are often discussed: level 1 up to 1000A, level 2 up to 2000A and level 3 up to 3000A. Initially, these MCS stations are likely to be level 1 (up to 1000A) at 1000VDC (1 MW) for on-road vehicles. Marine and electric aviation may have higher MCS power systems.
- MCS power levels could increase over time. For example, Europe has plans for 1500 A and 1000 V in the next 5-10 years, although there are vehicle battery technology challenges in accepting these charge rates.
- EVSE companies commented that MCS station sizes, at least through demonstrations, are likely to be up to 3MW allowing for low voltage (LV) utility connection. However, the expectation is station sizes would grow to require 9-12 MW to have sufficient charging for multiple, high power charging points. EVSE companies believed these high power sites would need medium voltage (MV) utility connections.
- The megawatt charging stations were also considered likely to be their own microgrids with the integration of energy storage and Distributed Energy Resources (DER).

- Bidirectional vehicle-to-grid integration (VGI) is expected to be offered eventually, or at least to allow power export to the grid from the microgrid supporting the MCS charging. However, bidirectional capability is not an initial priority.
- Energy storage and backup/prime generation support may be deployed to offset limited grid power and/or provide a lower cost electricity source during peak utility times.
- Charging efficiency improvements were seen as desirable for megawatt charging and this would promote a move to silicon carbide (SiC) based power electronics. SiC also has better temperature operating ranges, which can benefit thermal management designs. The additional benefit of a smaller footprint with SiC was seen as less beneficial. Although it was acknowledged that some sites may be space limited.
- Another feature of benefit was operational planning capability with fleets being able to reserve specific times to charge. This has benefits in allowing charging demand to become more predictable as well as potentially improving station utilization.
- Maintenance and reliability are seen as critical for truck charging, and EVSE companies are planning to incorporate remote monitoring and allow automatic resets and other features to improve uptime.
- EVSE unit costs on a $/kW basis are expected to be higher than CCS initially, but then reduce as volumes increase to be similar to CCS. No company suggested MCS would be lower cost.
- Maintenance costs are likely to increase due to the additional training and certification needed for technicians working on higher grid voltages and with microgrids incorporated into the systems. Although on a $/kW basis, the costs may be similar to CCS if not lower as the station power is significantly higher.
- The technology for megawatt charging is considered ready. The communication protocol needs to be finalized, prototype units developed and proven, and then production units can be designed and manufactured.
- Most companies believed the grid was not ready for megawatt charging, especially when station size goes beyond 3MW and is no longer LV connected. In EVSE company experience, new or upgraded LV utility service could take 1-2 years, and new or upgrade MV service could take up to 5 years.
- While companies believed megawatt charging would be adopted, there were concerns on the business case and affordability due to the higher total capital costs as charging power increases. This also led to some doubts that systems would need to evolve beyond 1 MW. Ultimately this will come down to the benefit fleets will receive from very high power charging.

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1 EVSE COMPANY INTERVIEWS FOR ETRUC PROGRAM

Background

The eTRUC program is funded by California Energy Commission with the following objectives:

- Understand the readiness of megawatt scale charging for electric trucks and buses
- Establish two demonstration sites in Southern California
- Plan for a network of megawatt charging to support trucking corridors.

A task under the program is to engage with industry stakeholders including truck OEMs and Tier 1 suppliers, EVSE manufacturers, and fleets. This report is a summary of interviews performed with EVSE companies to understand their plans and perspectives on megawatt charging. The companies engaged are all active in direct current fast charging (DCFC) today, supporting electric passenger cars, light commercial vehicles and medium and heavy-duty trucks and buses.

The interviews were held between February and May 2023. The EVSE manufacturers interviewed account for over 90% of the North American market. Due to the sensitive nature of this information, we committed to keep all responses anonymous and to only share aggregated data publicly.

The Purpose of the Interviews

Fast charging for commercial vehicles today has been an extension of the EVSE developed for passenger cars, and is usually based on the CCS charging connector and standard. We are now seeing deployments of medium- and heavy-duty electric trucks with significantly larger batteries than those used for light duty, and there is industry interest in moving to high power charging (megawatt scale charging) to enable these medium and heavy-duty trucks to recharge in short time periods.

An eTRUC program goal is to understand the readiness to be able to add 100 miles of range every 10 minutes. For a heavy-duty truck today, this would require a charging power of around 1.5 MW and would be a significant step up in power from CCS stations deployed today. The interviews with EVSE providers were to understand the status of planning and development for megawatt charging and its potential evolution path from today’s CCS charging.

2 DCFC CHARGING TODAY BASED ON CCS STANDARD

Most DCFC EVSE today follow the CCS standard which describes voltage and current levels as well as the design of the connector which plugs into the vehicle. The EVSE consists of two stages of conversion: (1) AC/DC rectifier stage which connects to the grid and feeds (2) a DC/DC stage which provides the commanded voltage and current to the vehicle. EVSE system designs broadly fall into two categories:

- Integrated. The two conversion stages are within the dispenser which receives the grid AC power. The integrated unit can also include battery energy storage as the example shown in Figure 1.
- Separate power cabinet (AC/DC stage) and dispenser (DC/DC stage). The dispensers are usually individually fed from the power cabinet. Although there are designs which have the dispensers on a DC bus provided by one or more power cabinets. This is illustrated in Figure 2.

Image from Freewire

Figure 1. Freewire integrated EVSE

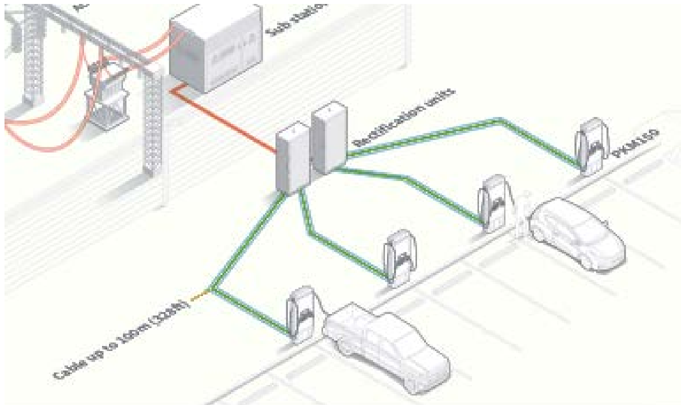

Image from Tritium

Figure 2. Illustration of separate power cabinet rectifier from DC/DC dispenser

The charging dispensers have a charging cable and connector which plugs into the vehicle. The connector has a specific design, conforming to a standard. Automotive has several standard connectors, but the most common type across cars and trucks is the CCS connector as shown in Figure 3. The combined connector allows both AC and DC charging. Since AC charging voltages vary from country to country there are two types of CCS connectors with CCS-1 using a U.S. standard for AC charging, and CCS-2 for European standard.

Image from Phoenix Contact

Figure 3. 500A rated CCS-1 charging connector

Energy storage can be included with EVSE to allow energy management. This storage can either be upstream of the AC/DC stage (on the AC side) or between AC/DC and DC/DC stages. Similarly, solar and other generation resources can be included. Most typically this integration of generation and storage resources is upstream of the EVSE and connected to AC. Some EVSE equipment products are bidirectional enabling power to be exported from the vehicles back to the grid, providing a vehicle-to-grid (V2G) mode of operation if fleets desire it.

The output voltage limit for CCS is around 950 VDC, which is the supply voltage from the AC/DC stage. The DC/DC stages are a buck architecture allowing the output voltage to be controlled down to 300 V or lower.

The dispensers commonly have air-cooled charging cables to connect to the vehicle, which can provide 300-350 A. Higher currents require actively cooled charging cables, with 500 A typically available today, although the EVSE companies suggested this can go to 700 A or higher.

The associated charging power levels depend on the vehicle voltage. For example, a nominal 800 VDC HD truck could receive 400 kW charging power from 500 A rated CCS charger. However the vehicle OEMs also specify the max current acceptance and today this can vary from less than 300 A to 600 A for trucks, which for the 800 VDC truck would imply a charging power of 240-480 kW.

In principle, two CCS charging connections could be made to the vehicle simultaneously enabling twice the charging power. This is a concept referred to as “double gun” charging. In practice, this would need a specialized design of the vehicle-based charging system as the standards require each charging connection to be isolated with appropriate sensing and protection.

Current annual volumes of CCS-based DCFC are in the few thousand per year range. However, with the plans to significantly expand public passenger car charging as well as more fleets moving to electric vehicles, this volume of CCS EVSE is expected to quickly grow to a few tens of thousands of chargers per year in the next couple of years.

Megawatt Charging

The electric commercial vehicle industry recognizes a need for EVSE capable of charging at power beyond the capability of CCS. This will take charging powers into the megawatt scale. Discussions and planning for megawatt charging are often associated with the Megawatt Charging Standard (MCS), which aims to define an across industry (on-road and off-road) standard for charging vehicles at megawatt scales. The MCS standard is being led by CharIN and has many industry partners in its working group. The MCS standard will define:

- The connector
- The communication protocols
- The operational limits (voltage and current)

An MCS connector and CCS connector are shown in Figure 4. As this is a high-power connector, it only provides DC, unlike CCS which has both AC and DC charging capabilities.

Figure 4. MCS charging connector (right) compared to a CCS charging connector (left)

The maximum output voltage limit for MCS was originally 1500 VDC and has now been revised to 1250 VDC to align with safety standards. The current limit is 3000 A and has been commonly discussed, non-officially, as three levels:

- Level 1 – 1000 A limit
- Level 2 – 2000 A limit
- Level 3 – 3000 A limit

These current and voltage limits result in the MCS standard being a pathway for charging at up to 3.75 MW (3000 A at 1250 VDC).

Conductive Automated High-Power Charging

Automated charging systems are becoming available for fleets who wish to remove the human interaction needed to connect and disconnect vehicles from the charging stations. These systems are currently used by transit bus fleets, mining operations, and at the ports. The EVSE are all defined in the SAE J3105 series of recommended practices published initially in January 2020 and revised in May 2023. These connector types shown in Figure 5 include:

- SAE J3105-1 Infrastructure-mounted Cross Rail pantograph with up to 1000 V and 450 kW
- SAE J3105-2 Vehicle-mounted pantograph (Bus-up) with up to 1000 V and 450 kW.
- SAE J3105-3 Pin and socket with up to 1000 V and 1.2 MW.

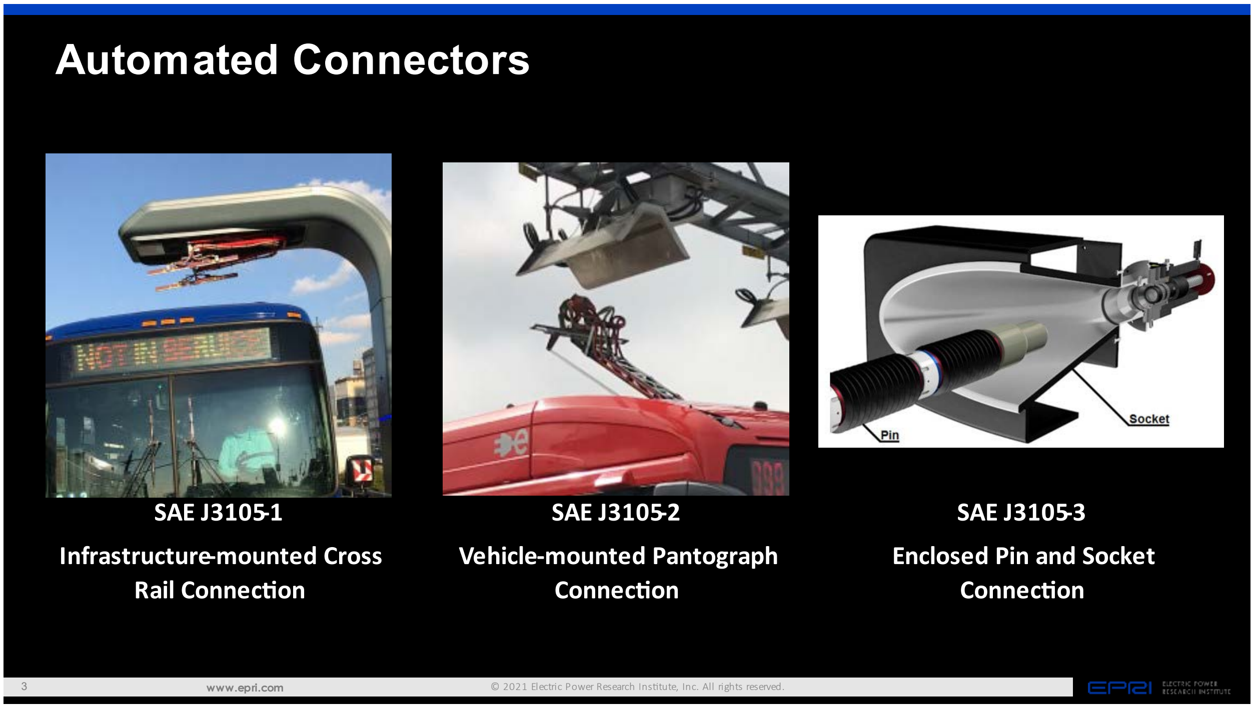

Figure 5. SAE J3105 series of connections

Inductive Automated High-Power Charging

High-power wireless is defined in SAE J2954-2. Two magnetic “pads” are used. One mounted on the ground and the other on the bottom of the vehicle. Charging power is provided by magnetic resonance when both pads are in close proximity. Currently, the power rating is 250 kW to 500 kW. An 8-10 inch gap between the two pads allows for good efficiency. See Figure 6.

Figure 6. SAE J2954-2 Automated Wireless Connection

3 PLANNING FOR MEGAWATT CHARGING

Almost all the EVSE companies interviewed are active in R&D on megawatt charging for trucks. The research activities identified during the interviews varied from designing prototype systems to actively monitoring developments. Although all EVSE companies commented that megawatt charging is still in the early stages of planning. All the EVSE companies are members of CharIN, the entity leading the development of the MCS standards.

Initial (prototype) EVSE systems using the MCS standard are expected to be deployed in the next couple of years. The EVSE companies did note that the standard has not yet been finalized for EVSE-to-vehicle communication and this is causing a delay in deployments. Another roadblock has been the availability of MCS charging cables and connectors, but there are now companies offering these.

Production MCS EVSE units will follow the prototype deployments and it was generally believed production units for sale could be expected in the 2027-2028 timeframe. There was also a view that MCS units will not become widely deployed until after 2030, since it will take time for the detailed planning and construction of MCS charging sites and corridors. In addition, electric trucks capable of megawatt charging will also need to be launched into production by vehicle manufacturers.

CCS to MCS Transition

The non-availability of MCS is not currently preventing sales of electric trucks, since the trucks can utilize CCS for charging, albeit with low charging rates. In time, the industry expects trucks, especially heavy-duty vocations, to move to megawatt charging to be able to charge faster. This transition from CCS to MCS will not just depend on megawatt charging equipment becoming available, but also on when CCS will no longer meet fleet charging needs. High current CCS designs are emerging, but most EVSE companies would expect CCS to be limited to around 500 kW charging. There is a possibility that two CCS charging cables (dual CCS) could be used in parallel to achieve up to 1 MW charging. However, most companies do not see dual CCS as the main path forward for heavy-duty trucks. This implies the expectation is that megawatt charging will be adopted for charging powers over 500kW.

The initial MCS stations being developed today appear to be level 1 (1000 A) with a maximum voltage of 1000 VDC. This equates to up to 1 MW of charging. This charging level also aligns with the charge acceptance capability of today’s truck battery packs.

There are plans to increase the MCS charging power in future. For example, Europe has a desire for 1500 A limit in the next 5-10 years, enabling European trucks to charge at up to 1.5 MW. Interestingly, EVSE companies have not yet heard interest from U.S. truck OEMs to increase beyond 1 MW charging.

There is also the possibility that trucks will use alternative charging connector types depending on the needs of fleets:

- CCS as an additional charging port to MCS on board trucks to provide interoperability with existing CCS chargers at depots.
- Pantograph, pin and sleeve, or high power wireless connectors instead of MCS at locations where a level of automated charging is required. As well as at depots, automated charging may become required as autonomous trucks become deployed in the more distant future.

MegaWatt Charging Station Designs

The initial megawatt charging systems are expected to use secondary service (low voltage) connected at 480 VAC. Utilities can allow secondary service up to 4000 A on three phases, which is around 3.3 MW. However, all the EVSE companies believed that power demand at megawatt charging sites would grow to 9-15 MW and this would require primary service (medium voltage).

The EVSE companies commented that a DC bus between power cabinets and dispensers could become desirable as this can improve reliability and resilience as well as provide a DC backbone to integrate energy storage and solar.

The MCS standard allows up to 1250 VDC, but initial systems will likely have a maximum of 1000 VDC. Going beyond 1000 VDC requires a change in power electronic components, and incurs significant additional costs. Since vehicle voltage is currently below 1000 VDC, the EVSE companies don't see the business case for offering 1250 VDC today. A consequence is any MCS stations deployed today will need to be upgraded to 1250 VDC in the future if truck voltages move to 1250 VDC, since a 1250 VDC truck will not be able to charge at a 1000 VDC charging station. This upgrade will incur costs and EVSE companies were not certain there would be sufficient benefit versus cost for the small increment in voltage from 1000 to 1250 VDC. Truck voltage migration to 1250 VDC was not anticipated before 2030, so there is time to understand the business case. Although it would be best if this is resolved before the MCS charging networks are built out, at least in key trucking corridors.

The dispensers themselves were expected to have both MCS and CCS charging cables and connectors to be able to support charging older trucks which would not have MCS. It was also noted that upgrading CCS cables and connectors to MCS in the future should be reasonably straightforward (for example, if MCS becomes completely dominant).

The megawatt charging plazas will be significant electricity load centers and there was an expectation that these charging plazas would be their own microgrids, potentially having the following capabilities:

- Bidirectional power capability to export power to local loads or to the grid distribution system.

- Stationary energy storage to provide energy management such as peak shaving.
- Integration of local electricity generation (DERs).

Bidirectional power flow to support vehicle-to-grid integration is technically possible. Views did vary on whether this would be needed. For example, V2G tends to be relevant for depot charging when vehicles might be connected to the charger for long idle periods (1+ days out of vehicle service) providing opportunity for V2G. MCS tends to be for fast charging of vehicles with only short periods connected to the charger. Hence V2G may not be desired in normal operations. Of course, emergency situations and power outages could benefit from charging sites providing local power from the electric trucks to the local grid. It was also recognized that there may be export power opportunities to the grid from any stationary energy storage or DER deployed on the charging microgrid.

Integrating energy storage will depend on the site design, energy costs, and any other (non-charging) loads the charging microgrid needs to support. Initial MCS sites are expected to be fully supported by the grid. However, using battery storage to peak shave demands is being utilized today for CCS charging and would be expected to have benefits for MCS deployments. If there are significant non-charging loads, then integrating the energy storage on the AC side may be more beneficial than on the DC side of the charging microgrid.

DERs are likely to include solar photovoltaic panels either in rooftop/canopy locations or adjacent fields. There can also be backup or primary power from fuel cell or internal combustion engine generators. Backup generation would support operations during grid outages, whereas primary generation would be used to either supplement the grid power during high charging demands, especially in weaker grid areas, or provide a lower cost of electricity during grid peak hours.

The optimum solution in terms of bidirectional power, energy storage, and DER support will be site dependent. Initial MCS systems may not have complete microgrid integration capabilities, but this can be provided in the future to meet customer requirements.

Initial megawatt charging designs are likely to use traditional technology such as dry transformers and standard power electronics. There is an expectation that silicon carbide (SiC) will become desirable for its improved efficiencies which will have more economic benefit at higher powers. However, SiC is expensive today. The SiC components can operate at higher temperatures which reduces the demand on EVSE cooling requirements. SiC also offers a potential reduction in the required EVSE footprint, although it was noted that not all megawatt charging sites are likely to be space limited.

EVSE companies also commented that megawatt charging designs will likely need to integrate with utility command and control due to the larger power demands. There will also be design refinements to ensure reliability and operation in all weather conditions as well as improving operational ergonomics and reducing audible noise (for example, from the EVSE cooling system).

EVSE companies also commented that scheduling of charging by fleets, for example by reserving charge times at public MCS chargers, would benefit management of charging loads as well as ensuring chargers are available. The reservation system could be web-based allowing fleets to book charging slots, and, in theory, the system could also link to fleet management tools. A reservation system is going to be trialled in European MCS deployments.

Maintenance and Reliability

Reliability will be critical for megawatt charging systems to support the trucking industry. EVSE companies commented that uptimes for EVSE will need to be 97+%, which is considered to be greater than the public CCS charging systems today. Reliability can be aided through remote monitoring and enabling automatic resets after trip-outs where possible.

There will also need to be support for planned and unplanned maintenance. There are two key differences identified for megawatt EVSE maintenance compared to CCS:

- Higher voltages, with the move from secondary to primary utility service.
- More likelihood that the EVSE is part of a microgrid including energy storage and DER.

The technicians providing the maintenance will need a broader knowledge set and certifications to work on the specific equipment of the higher power EVSE and microgrids.

Megawatt Charging Costs

The megawatt EVSE equipment will include features, such as specialized cooling, and the new charging cable and connector, which will add cost. The initial EVSE units will be low volume and hence be at a significant price premium compared to CCS units. Over time, the megawatt charging systems will likely reduce to be similar $/kW as CCS units.

None of the EVSE companies interviewed suggested MCS would be lower cost than CCS, and a cost premium may well remain if megawatt charging EVSE adopt SiC components for efficiency benefits.

Annual maintenance costs are likely to increase due to the additional training costs for the technicians. However, it is unclear if the maintenance cost ($/kW) would become lower than CCS due to the higher charging power. The majority of EVSE companies suggested maintenance costs would be similar to CCS.

The team plans to perform a detailed cost-benefit analysis for MCS in follow-on work as part of the eTRUC program.

MCS Readiness for Deployment

Technology Readiness

In all cases, the EVSE companies stated the technology is generally ready for megawatt charging. The key roadblock today (for demonstrations) is the finalization of the MCS standard for software protocols.

The expected rollout for demonstration units is in the next 1-2 years. Once the demo units are proven, production units could be developed and then become available a couple of years later.

Grid Readiness

All EVSE companies expressed concern about grid readiness for megawatt charging and the associated time required for utilities to make upgrades to provide service. Although there are some sites which have sufficient power, the experience of EVSE companies was around 1-2 years for sites to receive sufficient secondary service, with this time extending to up to 5 years if primary service was required. These lengthy utility upgrade times could slow down the deployment of megawatt charging and are causing some locations to consider using local natural gas-based generation to support the charging sites.

Business Case Readiness

While megawatt charging was considered to become the standard for heavy-duty trucks, buses, and off-highway vehicles, in the interviews there was uncertainty on the required specifications for the EVSE as there is a trade-off between the charging power and cost. The best business case for charging equipment is for the lowest power delivered and maximized utilization of the charging equipment. This tends to favor slower, depot charging rather than very fast public charging. There was speculation in the interviews whether high power (for example, well above 1 MW) would be considered affordable by fleets.

The EVSE companies expected that fleets will understand more about their economics and how they will want to utilize megawatt charging once the first few demonstration programs/pilot charging sites are operational.

Research Needs and Knowledge Gaps

The EVSE companies suggested several insights they would like to see come from the eTRUC program, which would help them plan their product offerings:

- Deeper understanding of megawatt charging needs within California.
- Updates on any regulatory or compliance requirements for megawatt EVSE systems.
- Utility power availability for megawatt charging within California.

- Expected charging capacity of MCS sites.
- Design requirements for dispensers. For example, the charging connectors needed, cable lengths, ergonomics, and display information.
- Requirements for interoperability with different trucks. For example, any differences that are expected from OEM to OEM or fleet to fleet.
- Availability of test labs and test sites which EVSE companies can benefit from to develop their equipment.
- Updates on fleet interest in alternative connector types to MCS, especially those supporting automated charging.

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