ABSTRACT
Electric trucks and buses are becoming a practical alternative for commercial vehicle fleets in certain vehicle applications, and growing pressure from shippers, regulators, and society to reduce fleet carbon footprint is prompting equipment users to consider alternatives to conventional diesel or gasoline internal combustion engines. This TMC Information Report provides an understanding of electrical vehicle designs and functionality. It covers the general physical, electrical, communication protocol, and performance requirements for the electric vehicle conductive charge system and coupler.

BACKGROUND
Electric trucks and buses are becoming a practical alternative for commercial vehicle fleets in certain vehicle applications, and growing pressure from shippers, regulators, and society to reduce fleet carbon footprint is prompting equipment users to consider alternatives to conventional diesel or gasoline internal combustion engines. Going forward, the typical fleet or owner-operator will require an understanding of the electric vehicle in its operations. Electric vehicles are becoming suitable for several applications — such as yard jockeys, delivery vans, mail or parcel vehicles and short haul vehicles. The knowledge for the use and maintenance of these vehicles differs completely from conventional vehicles utilizing diesel or gasoline internal combustion engines.

CURRENT INDUSTRY STANDARDS
The Society of Automotive Engineering (SAE) has modified its J1772 standard, “SAE Electric Vehicle Conductive Charge Coupler” (Figure 1). The standard defines electrical vehicle charge couplers and their performance characteristics, including voltage, current, and power levels. The updated standard includes additional levels and clarifications to ensure compatibility and interoperability among different electric vehicle charging systems.
Electric Vehicle Conductive Charge Coupler,” to include provisions for direct current (DC) charging. The latest revision of SAE J1772 was released in October 2012 and provides details on the charging protocol for DC off-board charging. The main updates to SAE J1772 are the elimination of 3-phase alternating current (AC) charging and DC Level 3 terminology. (See Figure 1.)

NOTE: AC L1 and L2 standards used today will stay the same. Limits for DC charging are defined in the SAE standard and do not apply to Chademo-based chargers. The Chademo standard defines only DC fast charging with a maximum output of 62.5kW and a DC output voltage range of 50-500V.

An AC L2 J1772 connector can also be used for DC L1 charging. (There are no industry plans to incorporate DC charging into existing or new L2 AC charging stations.) The combination DC connector is defined in the new standard and it is designed to support AC or DC charging. The pins on the top are populated with the same (five) leads as the smaller J1772 connector for AC charging and the pins on the bottom are for DC charging. (See Figure 2.) It is unlikely that the same connector will be used for AC and DC charging to charge safely.

SAE has adopted the DIN protocol for communications between the charger and vehicle. Messages will travel over the same control pilot wire and they are power-line carrier (PLC) based. The messages are embedded in the square wave of the control pilot signal.

EMERGING ELECTRIC VEHICLE MARKET

Interest in electric and plug-in hybrid vehicles is driven by elevated fuel costs, environmental consciousness, government incentives to foster energy independence, and the introduction of new electric vehicles (EVs) to meet future Corporate Average Fuel Economy (CAFE) standards. For truck and bus applications, the applicable CAFE standards are as follows:

- **Class 2b** - 5 vehicles, weighing 6,000-19,500 pounds GVWR, must meet 344 grams CO₂ per ton-mile and a CAFE rating of 33.8 gallons per 1,000 ton-mile for model years 2014-2018.
- **Class 6 and 7** vehicles, weighing 19,500-26,000 pounds GVWR must meet a CAFE rating of 204 grams CO₂ per ton-mile and 20 gallons per 1,000 ton-mile.
- **Class 8** vehicles, weighing 26,000 pounds to 33,000 pounds, must meet a CAFE rating of 107 grams CO₂ per ton-mile with a fuel consumption of 10.5 gallons per 1,000 ton-mile.

CALSTART estimates that there will be approximately 20,000 more EV truck and bus charging stations by the year 2016. According to Pike Research’s Third Quarter Electric Vehicle Charging Equipment Report, the number of global EV charging stations will surpass one million new installations in 2014.

Pike Research is a market research and consulting team that provides in-depth analysis of global clean technology markets. The team’s research methodology combines supply-side industry analysis, end-user primary research and demand assessment, and deep examination of technology trends to provide a comprehensive view of these industry sectors. (See Figures 3-6.)
There are also several trends influencing the adoption of both EV and hybrid electric vehicles:

- Urbanization
- Fuel price volatility
- Infrastructure limitations associated with other alternatives such as compressed and liquified natural gas
- Regulatory incentives and tax credits
- Improvements in energy storage technologies
- Global interest in environmentally sustainable technologies

(See Figure 7.)

**EV Advantages Versus ICE**

EVs have several advantages over internal combustion engine (ICE) powered vehicles:

- Improved fuel economy. Electric motors convert 75 percent of their input energy to power the wheels. Internal combustion engines only convert 20 percent of energy stored in gasoline and 45 percent stored in diesel.
- EVs are more environmentally friendly, with no tailpipe pollutants. This especially so when the electricity is generated from nuclear-, hydro-, solar-, or wind-powered plants. However, the production of electricity from fossil fuels does remain a greenhouse gas emissions concern. According to Frost & Sullivan, U.S. truck operation causes approximately 20 percent of the nation’s greenhouse gas emissions from transport activities. Making the switch to hybrids could save 300-700 gallons of fuel per year and pre-
vent three to eight tons of carbon dioxide emissions release.

- EV use helps reduce U.S. dependence on foreign energy. Electricity is a domestic energy source.
- EVs also feature:
  - quieter ride
  - smooth operation
  - stronger acceleration
  - lower maintenance than ICE’s

ELECTRIC VEHICLE TERMINOLOGY
There are several types of electric vehicle technology in current use:
- Hybrid Electric Vehicles (HEVs)
- Plug-in Hybrid Electric Vehicle (PHEVs)
- Battery Electric Vehicle (BEVs)

Hybrid Electric Vehicles
These typically combine the benefits of gasoline engines and electric motors. HEVs can be configured to achieve different objectives such as improved fuel economy, increased power, or additional auxiliary power for electronic devices and power tools. Advanced technologies often used in hybrid electric vehicles include:
- Regenerative braking—In this case, the electric motor applies resistance to the drivetrain causing the wheels to slow down. This, in turn, causes the wheels to function almost as a generator, sending the energy from the wheel turns to the motor. This allows for energy conversion rather than waste when coasting and braking.
- Electric Motor Drive/Assist—This provides additional power to assist the engine in accelerating, passing, or hill climbing, allowing a smaller, more efficient engine to be used. Sometimes the motor alone provides power for low-speed driving conditions, where internal combustion engines are inefficient.
- Automatic Start/Shutoff—In this case, the automobile automatically shuts off the engine when the vehicle comes to a stop, and restarts it when the accelerator is pressed, preventing wasted energy while idling.

HEVs have at least one — but can have more than one — electric motor. They also feature a small, high-power traction battery that is not recharged by the grid; it still uses gasoline or diesel to power the main engine. (See Figure 8.)

Plug-in Hybrid Electric Vehicles
PHEVs use batteries to power an electric motor and use gasoline or diesel to power an internal combustion engine. These vehicles use energy from the grid to run the vehicle all or some of the time. This not only reduces operating costs, but also petroleum consumption.

PHEVs can be charged by an outside electrical source, by the internal combustion engine, or via regenerative braking. These vehicles can also have varied configurations of power from the electric motor and the engine:
- Parallel—connects the engine and the electric motor to the wheels through mechanical coupling, that way both the electric motor and the engine can drive the wheels directly.
- Series—uses only the electric motor to drive the wheels. The Internal combustion engine is used to generate electricity for the motor.

PHEVs have at least one — but can have more than one — electric motor. They have a larger battery than the HEV that can be grid
When battery energy is depleted, the PHEV begins to function like a hybrid. (See Figure 9.)

Battery Electric Vehicles
BEVs use electricity stored in rechargeable batteries for fuel, replacing gasoline, diesel and other types of combustible fuels. Electric motors propel the vehicle, which can have zero emissions, depending upon the power source.

BEVs typically have one 100kW or larger electric motor (unless the vehicle is large or has four wheel drive). The battery is the sole source of power. To charge the battery, the vehicle needs to be plugged into an electrical outlet or charging device. Since BEVs are grid recharged, power level becomes important.

- Recharging time varies with the type and capacity of the battery and the output capacity of your electrical outlet.

BEVs employ an inverter/charger which converts AC to DC to charge battery and converts DC to drive the electric motor. BEVs feature a traction battery which gradually runs down as vehicle drives. The electric motor drives the wheels, not an engine. BEVs can have a direct gearbox or multispeed transmission, which can be used to directly drive wheels. Regenerative braking extends useful range of battery. (See Figure 10.)

Battery Chemistries
- Lithium Ion (Li-ion)—This is the most common for electric vehicles. Other batteries (lead acid and nickel metal hydride) cannot match the weight-to-power ratio of Li-ion. For example, the 2012 Nissan Leaf has a 24kWh lithium-ion battery pack that weighs 200 Kg (440 lbs). Compare lithium-ion energy to the energy density of gasoline at 13.11 kWh/Kg (33.7kWh per gallon).

- Lithium-titanate—This is known for being able to charge faster than Li-ion. It is used in passenger EVs as well as electric buses, such as the Mitsubishi i-MiEV, Honda Fit and Proterra Bus.

Battery Size
Battery pack sizes for all-electric medium- to heavy-duty vehicles typically range from 50-120kWh. The size varies depending on cost, weight, purpose and duty cycle for the intended applications.

Driving Range
Most BEVs can go about 40-100 miles before recharging. Heavy-duty EV manufacturers typically aim for an approximately 100- mile battery range from full charge. PHEVs combine a small ICE with batteries to increase driving range.
KEY INDUSTRY PARTICIPANTS
This section will describe various key industry participants associated with electric vehicle technologies.

Electric Power Research Institute (EPRI)
The Electric Power Research Institute, Inc. conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, non-profit organization, EPRI brings together scientists and engineers as well as industry experts to help address issues in electricity, such as reliability, efficiency, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies.

Automotive Companies
Automotive companies are involved in many aspects of electric vehicle design and engineering, such as:
- research
- engineering
- battery technology
- front-end integration (plug connection)
- compatibility testing

Automotive companies are interested in electric vehicle technology because of the uncertainty in future fossil fuel costs, the need to meet government regulations, and available tax incentives. Significant progress in battery technology has also made electric vehicles more economically feasible. Figure 11 illustrates the relationship of various manufacturers and EV customers.

Figure 11
Electric Vehicle Supply Equipment (EVSE) Manufacturers

EVSE manufacturers engage in manufacturing, engineering, research and development. There are three types: Level 1, Level 2 and DC Fast Charging.

Level 1 EVSE manufacturers provide charging applications up to 120 VAC and 16 Amps. Level 1 EVSEs are commonly in the form of a cordset (as shown in Figure 12) that is portable and connects the vehicle to an standard receptacle. However, 120VAC EVSEs can be permanently installed, providing a slower charge but one that is ideal for the small battery packs often found on PHEVs.

Level 2 EVSE provides charging applications through a 208V/240V AC using the same SAE J1772 connector. They require installation of the equipment and a dedicated electrical circuit. Level 2 EVSE can typically charge an EV battery overnight, making it ideal for some fleet facilities. (See Figure 13.)
ADC Fast Charging EVSE, which uses 3-phase AC input, enables rapid charging for places of heavy traffic, be they roadside or at public locations. DC chargers can be 200-480 VAC. (See Figure 14.)

An electric vehicle’s charging rate is determined by the vehicle, the battery type, and the type of EVSE. For light-duty fleet applications, Level 2 chargers typically provide 10-20 miles of drive range per hour of charging, while the DC fast chargers offer 60-80 miles of range in 20 minutes of charging.

Many medium- and heavy-duty vehicle manufacturers are adopting light-duty charging standards, or commercially available standards that were developed for other uses. However, there are EVSE manufacturers that are introducing alternative charging configurations, so EVSE options and performance could be different for these vehicles.