Powering the New Generation of Electric Vehicles: Issues and Challenges
By 2015, there may be as many as 1 million electric-powered vehicles on roads and highways in the United States. That’s the target set by President Barack Obama in his 2011 State of the Union address. Although skeptics question whether President Obama’s 1 million vehicle target is actually achievable by that date, automobile manufacturers are moving to bring electric vehicles (EVs) to the market as quickly as possible. In fact, it is estimated that over 20 different EV models will be available for sale in U.S. car dealerships by 2015.¹

The rapid and dramatic increase in the number of EVs on the road will bring about many changes, not the least of which is the deployment of an infrastructure to power this new generation of high-technology vehicles. Already, pilot programs are underway throughout the United States to install electric vehicle charging stations (EVCSs), timed to support the new EVs that are rolling out of dealer showrooms. Further, owners of EVs will require the installation of EVCSs where they garage their vehicles. Some calculations place the number of EVCS required to support a fleet of 1 million EVs at more than 2.5 million units.

The introduction of electric-powered vehicles presents significant growth opportunities for automobile manufacturers as well as the manufacturers of power systems used to build and fuel America’s new EV fleet. At the same time, the installation and maintenance of potentially millions of EVCSs presents logistical and training issues for the technology companies that manufacture and service such equipment. Finally, consumers are likely to seek reassurances regarding the safety of electric-powered vehicles and the systems used to charge them.

This UL white paper provides an overview of the general issues regarding the introduction of EVs, and reviews the various types of EVs and the technology components required to power them. The white paper then discusses potential issues related to the widespread deployment of EVs, including the development of an EV power structure, safety concerns addressed by regulations and consensus standards, and the training needs of designers, field installation specialists, and enforcement officials. The white paper concludes with a preview of prospective issues facing manufacturers of EVs and EV charging equipment.
Powering the New Generation of Electric Vehicles: Issues and Challenges

Electric Vehicles—A Technology Overview

The future outlook for growth in the use of EVs has never been brighter. The emerging alignment of environmental, economic and political concerns stemming from the continued dependence on imported petroleum and other fossil fuels has resulted in increased interest by consumers in electric-powered vehicles and increased investment by automobile manufacturers in battery and hybrid technologies necessary to power them. In addition, new corporate average fuel economy (CAFE) standards requiring vehicle fleets to achieve nearly 55 miles per gallon by 2025 are likely to drive growth and additional investment. This interest has been further stimulated by billions of dollars of federal funds directed toward research and development, market development programs, and even the deployment of a federal EV fleet.

Electric-powered vehicles have evolved significantly over the fifteen years since they were first introduced in the United States. Hybrid gas-electric vehicles (also known as a hybrid electric vehicles or HEVs) made their debut in the late 1990s with the introduction of the Toyota Prius and Honda Insight. HEVs typically include two separate propulsion systems, a conventional internal combustion engine and an electrical propulsion system, a combination designed to optimize fuel economy. By May 2011, 2.0 million HEVs had reportedly been sold in the United States. Although manufacturers continue to make improvements in the efficiency of their HEV models, major investments in electronic propulsion systems have shifted to the development of plug-in hybrid electric vehicles (PHEVs). Like HEVs, PHEVs typically have two separate and independent propulsion systems. What makes PHEVs different from HEVs is the presence of a rechargeable battery system that can be restored to a full charge by connecting the vehicle to a charging system. General Motors was the first to introduce a PHEV to the U.S. market in late 2010 with the debut of the Chevy Volt, but a number of other manufacturers plan PHEV introductions in the next few years, including Ford, Toyota, Volvo, Audi, Suzuki and Fisker.

Development efforts are also proceeding on all-electric vehicles, such as the Nissan LEAF. These battery electric vehicles (BEVs) are powered exclusively by rechargeable battery systems and do not include a conventional internal combustion engine. Energy is transferred to a vehicle either by plugging it into an electric supply or exchanging the vehicle’s spent battery for a charged one. Vehicles operated exclusively on battery power are possible due to advancements in battery technologies, with the current generation of lithium-ion battery systems offering higher power and energy densities, and providing greater driving ranges and increased acceleration.

A Review of EV Power Components

Beyond the technical sophistication of electric-powered vehicle propulsion, EVs require a complex system of electrical and electronic components to support the recharging of the vehicle’s on-board batteries. On the other side, an electrical system is required to provide the requisite power to recharge EVs. These on-board and off-board systems and components must be designed to integrate seamlessly with one another to ensure a safe, convenient and trouble-free experience for consumers.

On-board and off-board charging systems typically include some or all of the following individual components:

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At the same time, manufacturers are developing enhanced charging systems and components to take advantage of new technological innovations. For example, a new generation of batteries is being developed that will provide consumers with the ability to make reserve battery power available to utilities in response to peaks in demand (so-called vehicle-to-grid technology). Moving these and other innovations from the research lab to the field will require a variety of new connectors, cables, motors, inverters and other components essential to safe and dependable performance.

**Supplier Dynamics in Deploying an EV Power Infrastructure**

The commercial success of PHEVs and BEVs will depend on the deployment of a nationwide network of public and private charging stations that will allow consumers to safely and conveniently recharge vehicle batteries. Initial efforts in this area are already underway, notably the EV Project, a public/private program with approximately $230 million in combined federal government and private funding, that is slated to deploy nearly 15,000 charging stations in 16 cities in six states (Arizona, California, Oregon, Tennessee, Texas and Washington) and the District of Columbia through the end of 2011. EV Project partners Nissan and Chevrolet are also expected to cover the cost of installing residential chargers for buyers of the Nissan LEAF (an all-electric vehicle), and the Chevrolet Volt (a PHEV).

But estimates of the number of EVCS installations required to support a growing fleet of EVs greatly exceeds the scope of the EV Project. According to Pike Research, nearly 1 million charging points will need to be installed in the United States by 2015 to support PHEVs and other chargeable vehicles. Others use multipliers of between 0.5 and 2.5 charging units per EV to calculate the anticipated demand for EVCSs. For the fleet of 1 million EVs projected to be on U.S. roadways by 2015, these multipliers would project a short-term requirement of anywhere between 500,000 and 2.5 million EVCS.

Given the significant market potential in meeting the expected demand for EVCSs, it is not surprising that companies from diverse industries around the world are actively exploring ways to leverage new and existing technologies in support of the development of EVCS infrastructure and equipment. As an illustration, a 2010 UL webinar on electric vehicle infrastructure issues attracted more than 600 participants from across the United States and from countries around the world, including China, India, Brazil and the European Union. Companies represented at the webinar included...
automobile manufacturers, but also consumer electronics manufacturers, aerospace and defense contractors, industrial infrastructure equipment suppliers, electrical utilities and others. But the convergence of diverse technologies from global companies also presents a number of challenges for everyone involved. Manufacturers must develop and deliver individual products and components that not only conform with specified technical requirements, but which also work seamlessly with products designed and produced by manufacturers in other industries. Supply chain management practices of individual companies must be harmonized to the extent possible so that required products and components are delivered where and when they’re needed. Producers based outside of the United States will need to anticipate the potential logistical issues that come from working with partner companies in other parts of the world.

In addition to these challenges, manufacturers must also understand the specific codes, regulations and standards that will govern the design, installation and use of their products and components in their intended location. Finally, initial and continuous training and education programs for installers, service technicians, local electrical inspectors and other code authorities, first responders, and end users are necessary to minimize safety risks for all involved.

Codes and Regulations Addressing EV Charging Equipment Safety Issues

Foremost among the challenges in deploying an EV power infrastructure are potential fire and electrical safety issues. Indeed, according to a Summary Report of the U.S. National Electric Vehicle Safety Standards Summit held in Detroit, Michigan in October 2010, the issue of safety related to vehicle charging infrastructure was one of the three greatest concerns among summit participants. Specific safety concerns include issues related to the technical design and performance of EV charging equipment, the types and quality of components used in such equipment, installation procedures and maintenance requirements.

Safety concerns regarding EV charging equipment in the United States are primarily addressed through state and local regulations, which most often reference the National Electric Code (NEC, also known as NFPA 70), and consensus standards promulgated by the Society of Automotive Engineers (SAE), the National Fire Protection Association (NFPA), UL, and other organizations. These consensus codes and standards undergo continuous review and revisions to address previously unidentified concerns as well as newly introduced technologies. Enforcement is typically carried out at the local level by an “authority having jurisdiction,” which can include state and local fire marshals, fire and electrical inspectors, and building and public health officials.

The most important safety code covering EV charging equipment is the NEC, which is the basis for most state and local electrical and safety requirements. Specifically, Article 625 of the NEC directly addresses requirements for the design and installation of EVCSs and other EV charging equipment. Article 625 also includes an extensive glossary of terms related to EVs and EVCSs.

The primary intent of NEC Article 625 is to prevent users from being exposed to energized live parts, and to provide them with a safe EV charging environment. To achieve that objective, Section 625.5 requires that all electrical materials, devices, fittings and equipment associated with EV charging equipment be listed or labeled by a Nationally Recognized Testing Laboratory (NRTL) accredited by the U.S. Occupational Safety and Health Administration (OSHA). (The listing requirement is consistent with other sections of the NEC dealing with electrical and electronic equipment used in the federally regulated workplace.) Article 625 also includes the following requirements applicable to EV charging equipment:

- All EV attachment plugs, connectors and inlets must be listed or labeled for the purpose (Section 625.16)
- EV supply equipment must include an interlock that de-energizes an EV connector and cable when a connector is uncoupled from an EV (Section 625.18)
- EV supply equipment must de-energize when strain could lead to the rupture or separation of a cable from an electrical connector (Section 625.19)
- EVCSs must have a listed personnel protection system to protect against electric shock (Section 625.22)
The above discussion represents only a brief summary of the key provisions of NEC Article 625. Those involved in the design, permitting and installation of EV charging equipment are encouraged to obtain copies of the code and to thoroughly review Article 625 prior to commencing any work on EV charging equipment.

It is important to note that some state and local authorities may impose additional safety requirements on the design and installation of EV charging equipment that are unique to their jurisdictions. However, in most cases, local authorities strive to incorporate the NEC by reference in local electrical and safety codes to accurately mirror the technical provisions of NEC Article 625.

Consensus Safety Standards for EVs and EV Charging Equipment

UL, SAE, NFPA and other organizations have been working for more than 15 years to develop and adopt consensus standards appropriate to the safety issues related to EVs, EVCSs, and other types of EV charging equipment and charging components. In most cases, the technical requirements found in consensus standards are closely aligned with those found in the NEC, and existing standards undergo continuous review and revision. In addition, new consensus standards are being developed to account for emerging EV and EVCS technologies. For example, UL is currently developing new on- and off-board EV standards for wireless (inductive) charging and to accommodate vehicle-to-grid technology.

EV and EV charging equipment safety issues addressed in current consensus standards typically address one of three types of risks, as follows:

1. High voltage and current, that is, the risk of electric shock and/or fire
2. Environmental concerns, covering temperature, humidity, water, oil and dust
3. The equipment’s durability and resistance to vibration and abuse

Here is a brief summary of the current consensus standards for EVs and EV charging equipment:

- **UL 62, Safety of Electric Vehicle Cable**—This Standard covers cables used to supply power, signal and control to EVs during the charging process. EV cable consists of two or more insulated conductors, with or without grounding conductors, with an overall jacket

- **UL 2202, Safety of Electric Vehicle (EV) Charging System Equipment**—This Standard covers EV charging system equipment located on- or off-board a vehicle. Off-board equipment is connected to the vehicle by means of a flexible cord and an electric vehicle connector

- **UL 2231 (Parts 1 and 2), Safety of Personnel Protection Systems for EV Supply Circuits**—This Standard covers devices and systems intended to reduce the risk of electric shock to the user from accessible parts, in grounded or isolated circuits for charging EVs
• UL 2251, Safety of Plugs, Receptacles, and Couplers for EVs—This Standard covers plugs, receptacles, vehicle inlets and connectors rated up to 800 amperes and up to 600 volts ac or dc, intended for conductive connection systems

• UL Subject 2594, Safety of Electric Vehicle (EV) Supply Equipment—This subject Standard covers equipment intended to provide power to an EV with an onboard charging unit. Specific products covered by Subject 2594 include EV power outlets, EV cord sets and EV charging stations

• UL Subject 2735, Safety of Electric Utility (Smart) Meters—This subject Standard covers electric utility meters designed to measure, monitor, record, transmit or receive electrical energy generation or use consumption information. Such meters may be used as a standalone device or as part of an EVCS

• UL Subject 2750, Wireless Charging Equipment for Electric Vehicles—This subject Standard covers products used in the systems for wireless charging of electric vehicles, including the primary and secondary coil units, and the power source. These systems are rated at a maximum 250 V ac

• SAE J 1772, Electric Vehicle and Plug-In Hybrid Electric Vehicle Conductive Charge Coupler—This SAE Standard addresses the configuration of the charge coupler, including the pin configuration, dimensions and overall design of a connector. SAE J 1772 references UL 2251 regarding coupler safety requirements

The Role of Testing and Certification
As previously noted, compliance with the provisions of the NEC requires that EVCSs and other EV charging equipment be listed or labeled. Such listings are typically achieved through testing by an accredited testing laboratory, in which representative samples of equipment are evaluated for compliance with the technical specifications and performance criteria detailed in relevant consensus standards. Equipment that is found compliant with the consensus standards is then published in the testing laboratory’s listing of approved or certified products and is labeled as proof of that certification.

The testing and certification of EVCSs and EV charging equipment and components are key elements in the overall safety of the EV power infrastructure. Testing by an experienced, independent third-party laboratory supports claims that a product has been rigorously and objectively evaluated for safety, both with respect to design and use, even under conditions not anticipated by a manufacturer. Rather than slowing time to market, the certification of products by UL or another NRTL can actually speed product acceptance by purchasing authorities and local enforcement officials.

The Importance of EV and EV Charging Equipment Training
In addition to safety issues related to the EV charging infrastructure, attendees at the 2010 U.S. National Electric Vehicle Safety Standards Summit cited training as a key ingredient in the successful and safe introduction of EVs into widespread use in the United States. Summit participants focused exclusively on training for local enforcement officials and first responders. But training and education efforts will necessarily reach beyond this group to include designers of charging systems, electricians and field installation specialists, maintenance technicians, local code officials and others.

As an example of the training already available or in planning stages, UL has announced an initial curriculum of three separate e-Learning courses/webinars, as follows:

• Electric Vehicle Charging Station Infrastructure Design—For construction engineers, architects, municipalities and property owners, this course provides a comprehensive overview of
EVCS technology, and design considerations for large-scale installations

- **Electric Vehicle Charging System Installation**—For experienced and qualified electricians, this self-paced course covers the entire EVCS installation process. Participants who pass a comprehensive online assessment following the course are awarded UL’s EVCS Installer certificate

- **NEC Article 625—Electric Vehicle Charging Stations for Code Officials:** For code officials responsible for permitting and inspecting EVCSs, this webinar provides an introduction to EVCS technology, equipment and installation requirements, as defined in NEC Article 625

UL is in the process of developing additional training programs, consisting of both e-Learning, classroom instruction and hands-on training.

These and other courses and training options are essential to support the full-scale rollout of EVs over the coming decade and to foster the development of skills necessary to install and maintain the required EV power infrastructure. Equally important, training and continuing education programs focused on EVs and EV charging systems can support efforts to encourage employment and job growth in so-called green technologies, providing work opportunities for thousands of workers.

**What’s Ahead for Manufacturers?**
The market for electric-powered vehicles and the energy systems that power them will grow dramatically in the coming years. While it is impossible to predict the future with any degree of certainty, here are some thoughts on the likely consequences ahead for manufacturers.

**The Industry Will Grow Quickly**
Political turmoil and rising energy prices will eventually spur consumer demand for EVs, and manufacturers will struggle initially to keep up. This dynamic will attract an abundance of new market entrants, ranging from small technology start-ups with innovative ideas to large corporations looking to exploit their resources to capture share in this new market. New players are likely to come and go at a startling rate, and production overcapacity is a potential risk.

**More, Not Less, Regulatory Oversight**
Federal regulations already control most safety issues related to EVs, but the rollout of a national EV power infrastructure will largely be governed by state and local enforcement officials. Politics aside, the consequences for regulators who miss a potentially catastrophic safety risk related to the EV power infrastructure are too great. Look for more, not less, attempts at federal oversight in this area.

**Product Safety Will Drive Market Acceptance**
As noted throughout this white paper, safety issues related to the vehicle charging infrastructure is the pre-eminent concern among all stakeholders, including the general public. Manufacturers who place product safety ahead of all other concerns, by designing safe products and submitting them for testing and certification, will build trust among consumers and earn a reputation for quality.

**Knowledge and Training Are Essential**
Knowledge and training are key to the successful deployment and acceptance of any new technology, and EVs and EV charging systems are no different. Manufacturers and other stakeholders must commit to training and education programs to ensure that their products are designed, certified, installed, maintained and used as efficiently and as safely as possible.
Conclusion

In just a few short years, the prospect of EVs as a viable alternative to gasoline-powered vehicles has become a reality. The deployment of a nationwide power infrastructure to support the growing fleet of EVs will provide manufacturers with abundant new opportunities, but those opportunities will come with additional challenges, the most important of which is the safe operation and use of EVs and EV charging systems. This challenge can best be met by the continued active advancement of appropriate regulations and consensus standards, a rigorous testing and certification program, and a commitment by manufacturers and other stakeholders to provide comprehensive training and education options for all involved.

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