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Author(s): Mark Rawson and Sue Kateley
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Electric Vehicle Charging Equipment Design and Health and Safety Codes

Mark Rawson and Sue Kateley
California Energy Commission

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ABSTRACT

Any new technology has impacts on the industries, government and consumer sectors that have dealings with it. Introduction of significant numbers of electric vehicles (EVs) and the need for installation of charging equipment to support them has caused concerns for building department personnel, equipment manufacturers and installers, consumers, EV pioneers, government agencies and others.

This paper presents a summary of California's Health and Safety Code requirements for Electric Vehicle Supply Equipment (EVSE) and how equipment has been developed to comply with it. Background, history, rationale and comparisons are given for requirements in the California Health and Safety Codes, and 1996 and 1999 National Electrical Codes® (NEC®).

INTRODUCTION

In 1991, a national consortium of automakers, equipment manufacturers, building officials, utilities and government officials began addressing issues facing EV charging. Called the National Electric Vehicle Infrastructure Working Council (IWC), the consortium began parallel efforts to develop vehicle and charging equipment using a systems approach. The outcome of their efforts was equipment and safety standards that result in equipment which uses technology to handle shock hazards and battery hydrogen off-gassing. IWC recommended these standards to the Institute of Electrical and Electronic Engineers, the National Fire Protection Association (NFPA), the American National Standards Institute, the Society of Automotive Engineers (SAE), and Underwriters Laboratories (UL).

More specifically, the SAE developed equipment standards that detail operational and architectural specifications for charger and vehicle components. UL developed safety standards for listing of charging equipment. The NFPA adopted safety standards in the form of the 1996 NEC® and more recently the 1999 NEC®.

In 1994, the California Energy Commission (Energy Commission) began working with IWC, California Building Officials and the State Fire Marshal to modify the 1996 NEC® Article 625 to accommodate California specific issues and adopt it prior to California's normal triennial adoption schedule. In June 1996, a modified version of the 1996 NEC® Article 625 became effective as the California Electrical Code's new Article 625. At present, California is looking at adopting the 1999 NEC® Article 625.

In order to understand how the building codes came to be and what they require, it first is important to understand what issues precipitated their development and how the equipment and vehicles function. This will be followed by a discussion of the building codes and how they are enforced. Finally, changes reflected in the 1996 NEC® will be discussed.

CHARGING EQUIPMENT DEVELOPMENT

SAFETY IS FOREMOST – Safety was and is the primary reason charging equipment and safety standards have progressed in the direction they have. Related to this is the issue of liability.

Some EV enthusiasts assert that existing plugs and receptacles, such as NEMA 14-50R or -30R, provide sufficient safety for an EV application. As far as we know, this claim is unsubstantiated by any independent testing. While RVs, clothes dryers, welders and so on use these receptacles, the duty cycle of these items do not compare to that of EVs. With EVs, regular connection and disconnection of the vehicle to the charging equipment happens twice a day at a minimum (e.g., when leaving home in the morning and when returning in the evening). When public or workplace charging is used, this number can be more.

Clothes dryers and welders on the other hand are typically plugged in when installed and are not unplugged until removed (e.g., once or twice over a span of years). Even portable welders are not moved with great daily frequencies. RVs on average are only temporarily used

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(e.g., during vacation periods each year). As such, they do not get plugged in and unplugged daily throughout the year.

California wants 35,000 EVs operating in California by 2003. This would equate to 25.6 million connections/disconnections per year. Potential for an accident to occur where someone inadvertently touches an energized plug that is partially inserted into a receptacle is greatly increased. Therefore, the connection method for EVs to the off-board equipment must be fool proof.

"SMART" CHARGERS – Advanced technology is used in order to make charging equipment that is fool proof and provides the minimum levels of safety specified by the safety experts collaborating through the IWC.

There are four basic safety devices that are required by the 1996 and 1999 NEC® to meet the minimum safety requirements specified by the safety experts. These are:

- Connection Interlock
- Charge Circuit Interrupt Device
- Automatic Deenergization Device
- Ventilation Interlock

These components, how they operate, and where they are specified in the codes will be discussed in *Safety Devices*. Because charging equipment manufactured to meet the code requirements have these devices, they have been called "Smart" Chargers. They are considered smart because they communicate with the EV prior to and during charging to detect any anomaly that might affect safety or the equipment.

DURABILITY AND VALUE – Second to the safety issue is durability and long term value for the consumer. Because plugs and receptacles must be capable of withstanding high numbers of mate/demate cycles, they must be durable. Some plugs and receptacles, like the NEMA 14-50R or -30R are not designed to withstand the duty cycles of EVs and would probably require more frequent replacement or repair resulting in higher life cycle costs to the consumer and possible safety hazards due to deterioration of the plug and/or receptacle. In addition, these plugs and receptacles must be durable in all weather conditions, including wet, corrosive, and adverse temperature conditions.

The Electric Power Research Institute conducted durability tests on a variety of plugs and receptacles for EV charging. The tests found the inductive systems and butt/pin contactor configurations more resilient to the demands of the EV duty cycle and operating environment than other common plugs/receptacles contactor configurations.

Finally, the customer will have the greatest opportunity to take advantage of discount energy supply rates through the use of Electric Vehicle Supply Equipment (EVSE) that can be programmed to charge vehicles during lower rate periods allowed by their electricity provider. These lower time-of-use rates are available through most California electricity providers. This benefits all electricity users by encouraging charging during off-peak demand periods when generation capacity exceeds demand.

Overall, this systems approach to EVSE design provides for safety, durability and value to owners of electric vehicles, and to others who use electricity in the same service region.

CONFIGURATIONS – Driven by safety and life cycle cost, electric utilities and automobile manufacturers have evaluated several different methods of connecting EVs to off-board equipment for charging. Table 1 below defines the different charging levels industry has formalized for EV charging. Figure 1 below shows the three configurations considered.

Table 1. Charging Levels [1]

Level 1	"Level 1" EV charging employs cord & plug connected portable EVSE that can be transported with an EV. This equipment is used specifically for EV charging and shall be rated at 120 VAC and 15A, and shall be compatible with the most commonly available grounded electrical outlet (NEMA 5-15R).
Level 2	"Level 2" EV charging employs permanently wired EVSE that is operated at a fixed location. This equipment is used specifically for EV charging and is rated at less than or equal to 240 VAC, less than or equal to 60A, and less than or equal to 14.4 kW.
Level 3	"Level 3" EV charging employs permanently wired EVSE that is operated at a fixed location. This equipment is used specifically for EV charging and is rated at greater than 14.4 kW.

In order to accommodate unique situations from charging site to charging site and perhaps to make charging EVs analogous to refueling a gasoline vehicle, industry has adopted the Off-board Cord/Connector option as the connection method for Level 2 and Level 3 charging. Level 2 is the most prevalent charging level and can be found in the home, workplace or public sites. Level 3 charging will be less common and will be used for certain fleet applications and/or retail public charging sites.

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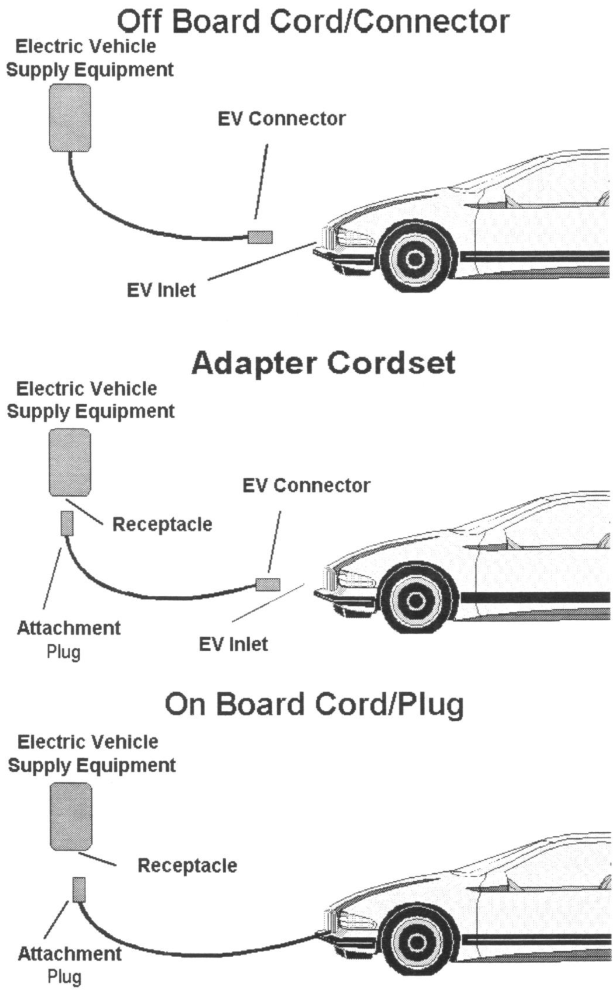

Figure 1. EV Connection Alternatives [2]

As can be seen in Table 1, Level 2 and 3 charging equipment are intended to be permanently wired in place. This allows for the charging equipment off-board the vehicle to be sized for the level of charging it can provide. For example, for Level 3 charging, the cable and conductors will be sized larger to handle the higher amperages required. The On-board Cord/Plug option for Level 2 and 3 charging would require this large cable to be on-board the vehicle, thus increasing vehicle weight and reducing driving range. The Off-board Cord/Connector option on the other hand, minimizes the on-board cabling, thus minimizing weight while still allowing for Level 2 and 3 charging to occur with the same inlet on the vehicle.

Level 1 charging takes a long time because the power level is low. Consequently, Level 1 systems are typically only used to charge in situations where a Level 2 system is not available. The Adapter Cordset option has become the preferred method of connecting Level 1 charging systems. Because it is intended to be used in unexpected locations and circumstances, Level 1 systems are designed to plug into common outlets found anywhere (e.g., NEMA 5-15R or -20R). Put another way, it is designed to not require specialized equipment yet still provide minimum safety provisions in the form of grounding and ground-fault protection. Again, Level 1 charging will probably not be the long-term, preferred method of recharging vehicles in a scenario where many EVs are in use.

SAFETY DEVICES – As discussed earlier, there are four main safety devices incorporated into "Smart" EVSE that make for fool proof, safe operation. These devices are a Connection Interlock, Charge Circuit Interrupt Device (i.e., ground-fault protection), Automatic Deenergization Device, and Ventilation Interlock. While each device serves a specific function, they work together as a system to provide a seamless charging event. While Level 2 and 3 employ all four of these components, Level 1 charging only uses ground-fault protection. The other devices are not required because the risk of shock from plugging and unplugging a Level 1 system is no greater than for common household appliances. For Level 2 and 3, all four devices are required because the shock hazards are higher and more potentially lethal.

Connection Interlock – The Connection Interlock is a device that provides for a dead interface between the EVSE and the vehicle. When the EV Connector is not connected to the vehicle, the Connection Interlock prevents power from being applied to the cable or EV Connector. When the EV Connector is connected to the vehicle, a signal is passed from the EVSE to determine if a vehicle is connected and the EVSE performs a systems check. Subsequent to confirming system integrity, the EVSE allows energy to flow through the cable and connector. This device is required by Section 625-18 of the 1996 and 1999 NEC®, and California Electrical Codes.

Charge Circuit Interrupt Device – Ground-fault protection is required for all charging levels by Section 625-22 of both the 1996 NEC® and the California Electrical Code. Specifically, the codes require ground-fault protection devices for personnel so that "when a current to ground exceeds some predetermined value that is less than the current required to operate the overcurrent protective device of the supply circuit, the system shall de-energize the electric vehicle supply equipment within an established period of time."[3]

Traditional Ground-Fault Circuit Interrupters (GFCIs) for 60 Hertz systems trip at 5 milliamperes (mA) when they detect a possible ground-fault current. This trip level avoids electric shock that can result in any harmful effects including the effects starting at 5 mA (immobility of body muscles, respiratory arrest) and the effects that could occur at 20 mA (ventricular fibrillation). However, these GFCIs cannot differentiate between possible hazardous ground currents and harmless transient currents on the electric utility distribution system (typically not greater than 20 mA). Therefore, traditional GFCIs are subject to "nuisance tripping" if a transient current above 5 mA occurs.[4]

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To remedy the situation, the personnel protection systems for EVSE use ground or isolation monitoring, a circuit interrupting device, and basic, double, or reinforced insulation. Product safety standards developed by UL specify what combinations of these devices can be used to meet personnel protection requirements. For example, basic insulation and a traditional GFCI that trips at 5 mA can be still be used, but “nuisance” tripping may be a problem as explained above. To avoid nuisance tripping problems, a 20 mA tripping circuit interrupting device can be used in conjunction with double or reinforced insulation. A 20 mA tripping circuit interrupter can be used with basic insulation also, but a ground monitoring device must be used as well. These combinations are applicable to 240 volt or smaller systems (Level 1 or 2 charging). For Level 3 systems, additional constructional features are required.

“Isolated systems (with no intentional system-grounding connection) can be used if the isolation is reliable. One way to make isolation reliable is to monitor the isolation and disconnect power if a ground-fault appears anywhere in the system.”[5] Consequently, UL standards allow for use of basic insulation in conjunction with an isolation monitor. For Level 3 systems, additional constructional features are required.

Circuit interrupters that trip at 20 mA prevent ventricular fibrillation, and special constructional features handle the shock effects (e.g. muscle tetanization, respiratory arrest) or transient currents below 20 mA,. In this way, advanced personnel protection systems used in EVSE can distinguish between hazardous ground currents and harmless transient currents to offer a level of protection better than traditional GFCIs with fewer occurrences of nuisance tripping.

In the 1999 NEC®, Section 625-22 has been changed to allow for a systems approach to providing protection versus a device only approach.

Automatic Deenergization Device – The Automatic Deenergization Device is a mechanism that will deenergize the EVSE if a strain occurs to the cable or EV connector that could result in live parts being exposed. An example would be where a parked EV connected to a charging station accidentally rolls back resulting in strain to the cable. This device is required in Section 625-19 of the 1996 and 1999 NEC®, and the California Electrical Code.

Ventilation Interlock – With conventional starter batteries used in gasoline vehicles and some conversion EVs, hydrogen gas can be generated during charging. In EVs marketed by major automobile manufacturers, advanced batteries are used that do not generate hydrogen gas. To avoid creating a situation where hydrogen gas can collect in an enclosed space, such as a garage, the codes require a ventilation interlock.

The ventilation interlock performs three functions in order to meet the requirements of Section 625-29 of the 1996 and 1999 NEC® and section 625-29 (c) and 1206 of the California Electrical and Building Codes. First, it queries the vehicle to determine if the vehicle requires ventilation during charging. Second, it determines whether the EVSE can provide ventilation. Finally, if ventilation is available, it ensures the ventilation operates during the entire charging process.

Three scenarios illustrate how the ventilation interlock operates:

1. If a charging station has ventilation included in the system, then the interlock will allow either a gassing vehicle (i.e., a vehicle using gassing batteries) or nongassing vehicle to charge.
2. If a charging station is located outdoors where there is sufficient natural ventilation, the interlock will allow either vehicle to charge.
3. If ventilation is not included in the system, then the interlock will allow a nongassing vehicle to charge, but not a gassing vehicle.

The ventilation interlock provides assurance to the EV owner that hydrogen gasses, if generated, will not collect in enclosed spaces regardless of the type of batteries or vehicle. This assurance provides for the long-term market success of commercially produced EVs.

BUILDING STANDARDS

NEC® COMPARED TO CALIFORNIA ELECTRICAL CODE – California adopts codes and revisions on a triennial basis. In 1995, California adopted the 1993 NEC® as the California Electrical Code and approved including Article 625 of the 1996 NEC® in the California Electrical Code as well. Therefore, the 1996 NEC® Article 625 is the basis for the 1995 California Electrical Code Article 625. However, California also modified the provisions in the 1996 NEC® Article 625 in two important ways.

First, California only requires "approved" equipment as opposed to "listed". Listed means the equipment has been tested by a nationally recognized testing facility such as UL to perform to certain performance standards. In the case of EVs, the charging equipment is listed to comply with NEC® Article 625. At the time of adoption, availability of listed Level 3 charging equipment was uncertain. Since the codes do not specifically differentiate between Levels 1, 2 or 3, California did not want to hinder the installation of Level 3 charging equipment for large EV applications such as buses. Therefore, California allows the jurisdictions having authority (e.g., individual building departments) to approve equipment and installations based upon their own assessment of whether it meets the requirements of the code. This can be done by showing manufacturer's data or third party testing (for example UL) that proves the equipment meets the safety requirements of the code. Practically speaking however, most building departments require the equipment to be UL listed for the purpose intended. California is likely to require listing after it adopts the 1999 NEC®.

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The second major change between the 1995 California Code and 1996 NEC® is ventilation. In the 1996 NEC®, ventilation requirements are included. In the California Code, ventilation requirements pertinent to EVs have been moved to the appropriate sections of the California Building Code. This was done so that ventilation, whether EV related or not, is addressed in the same sections of the California code.

WHAT'S COVERED BY THE CODES – The scope of the NEC® and California Code applies to all the equipment that supplies power between the electricity provider and the EV. This means a simple receptacle would also be under the requirements of NEC® Article 625 if it is intended to be used as a power supply for an EV. The 1996 and 1999 NEC® and California Article 625 define EVSE as:

"**Electric Vehicle Supply Equipment**. The conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle."[6]

Figure 2 shows how EVSE, premise wiring, the vehicle and the utility all interface with one another. In this context, it is easier to discuss the role building departments play in permitting EV charging installations.

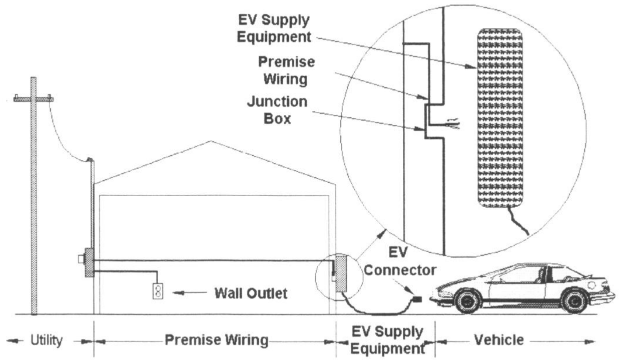

Figure 2. EV Charging System Configuration [7]

CODE COMPLIANCE – The definition of EVSE means the building department generally has jurisdiction over all premise wiring from the service panel to the interface with the EV. In the case of Level 2 and 3 charging where the equipment is hardwired in place, this is clear and unquestioned. The building department enforces the provisions of the codes in these instances. Since in most cases the building inspectors will not see the EV during field inspection and because the EVSE is designed not to operate unless connected the an EV, building officials rely on the UL listing process to validate that the EVSE meets the safety provisions of the building codes. They then can treat the EVSE as any other household appliance.

First, they verify the proper equipment is specified in the plans by checking the UL listing. With a charger listed for use indoors without ventilation, the building official knows ventilation will not be required. The building official relies on the UL listing to ensure the charger will only charge nongassing vehicles. Furthermore, because major manufacturers are using charging systems that communicate with the vehicle, building officials rely on the UL listing to ensure a nonventilated charging station will not accidentally charge a gassing vehicle. Second, they verify the premise wiring and required circuit breakers are sized and installed properly. Last, during field inspection, they verify the charging equipment is installed per the manufacturer's instructions.

Level 1 charging systems are more difficult to address however. By design, Level 1 charging equipment is configured to use conventional wall plugs, not specialized equipment. In most cases Level 1 Cordsets are provided with the vehicles. Consequently, building department inspectors are not likely to see a permit application for Level 1 EVSE. However, the code requirements are still required and a permit should be obtained for Level 1 EVSE.

CODE TRAINING PROGRAMS – To date, over fifteen training sessions have been held for over 250 California building department personnel. These classes have been conducted by California Building Officials Training Institute. The training materials cover:

- Technology Overview
- Plan Check Issues
- Communication Issues between Plan Check and Inspection
- Permitting Guidelines
- Code Definitions
- Inspection Issues
- Manufacturing Issues
- Inspection Guidelines

The California code development and training program was sponsored by California Electric Transportation Coalition, Los Angeles Department of Water and Power, Pacific Gas and Electric Company, Sacramento Municipal Utility District, San Diego Gas and Electric Company, Southern California Edison Company, Hughes Power Control Systems, General Motors Corporation, California Air Resources Board, and the Energy Commission.

For more information about the codes or training, contact California Building Officials Training Institute at (916) 457-1103 or www.calbo.com.

OTHER 1999 NEC® CHANGES – Beside the various changes discussed previously in this paper, three more changes that will take effect with the 1999 NEC® should be mentioned.

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The first change deals with ventilation. In the California and 1996 NEC® codes, ventilation is emphasized as the requirement (i.e., the rule) with exceptions for using equipment safe for use indoors without ventilation. Since these codes became effective, all of the major automobile manufacturers are using nongassing battery technology and "smart" chargers. As such, ventilated charging systems are not required. In effect, "no ventilation" has become the rule and "ventilation" has become the exception to the rule. Therefore, to reflect this, the 1999 NEC® will emphasize ventilation not being necessary except in certain instances. Because the equipment has a ventilation interlock and is UL listed, building officials and consumers can rest assured that a nonventilated charging station will not inadvertently charge an offgassing vehicle if the EVSE cannot provide ventilation.

The second change deals with marking of the equipment. In previous editions of the codes, there was confusion about who is responsible for the markings on the EVSE. Is it the responsibility of the automobile manufacturer, equipment manufacturer, or installation contractor? Where should the markings be located? Does every piece of equipment have to be marked? The new changes to the code clear up these questions by detailing where markings are to be placed and by whom. Furthermore, three separate marking requirements have been moved to one place in the codes, Section 625-15. Generally, all EVSE is to be marked by the manufacturer "For use with Electric Vehicle".[8] The two ventilation requirements that used to be in Section 625-29 deal with the ventilation requirements of a particular installation. As substantiated by Dave Brown, coauthor of the 1999 NEC® code language, "the wording was changed to make it perfectly clear that when ventilation is required, the EVSE installation must be marked accordingly [by the manufacturer], and an exhaust fan must be installed. When ventilation is not required, the EVSE installation must be so marked [by the manufacturer] and no exhaust fan is necessary."[9] Whether marked "Ventilation Required" or "Ventilation Not Required", the markings are to be placed so that they are clearly visible after the installation.

The last change of note deals with how EVSE is installed. Earlier code versions did not clearly reflect the specifications outlined in the IWC Record of Consensus items shown in Table 1. EVSE is intended to be permanently installed, meaning the equipment is permanently fastened to a wall or bollard, and the wiring is hardwired in a junction box or some similar fashion. Level 1 EVSE is permitted to be cord and plug connected as long as it has ground-fault protection. The 1999 NEC® language specifies all EVSE is to be permanently connected and fastened in place except equipment rated 125 volts, 15 or 20 amperes which can be cord and plug connected.[10] This means Level 1 EVSE.

CONCLUSION

Through a national effort, EV charging and supply equipment has been designed with safety as the primary concern. Using advanced technology to overcome safety concerns, industry has developed safe EVSE that is durable and convenient to use. Safety requirements have been incorporated into various standards including equipment standards with the SAE and UL, and safety standards with NFPA, the NEC®, and California Building Codes.

The NEC® and California Building Codes require four main safety devices and constructional features to address shock hazards and battery offgassing concerns. The codes require only approved or listed equipment be used for charging EVs.

The 1996 NEC® was a proactive attempt to develop codes for equipment that was new, not readily available, nor widely disseminated yet. After evaluating consumer preferences, building department practical experience permitting installations, and changes or enhancements in EVSE design, the 1999 NEC® clarifies areas of the original code to make the process easier and more understandable for building officials, installers and consumers.

ACKNOWLEDGMENTS

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CONTACT

Mark Rawson has been working for the California Energy Commission for 5 years as an Associate Mechanical Engineer. His duties have included development of equipment specifications and documentation for methanol fuel and electric vehicle infrastructure, development and implementation of statewide building standards for the safe installation of electric vehicle charging systems, and development and implementation of an electric vehicle emergency responder training program. Mr. Rawson has actively participated in several National Electric Vehicle Infrastructure Working Council committees to address health and safety, and power quality and distribution issues. At present, he is managing a program with the National Electric Energy Testing, Research, and Applications Center and California utilities to assess the power quality impacts of electric vehicle chargers on utility secondary distribution systems. He is also managing a demonstration of small-scale methane liquefaction plants to support heavy-duty truck demonstrations coming to California over the next few years. Mr. Rawson received a Bachelor of Science Degree from California State University, Chico in 1989.

Sue Kateley manages the electric vehicle program at the Energy Commission. Sue has been with the Commission for nearly 15 years and served in the Energy Efficiency Division developing standards for new homes. Following that, she served as a Legislative Analyst for the Commission. In 1992 she was the principal author of the Governor's Energy Policy report. It was the research done for that project that led Sue to seek a position supporting California electric transportation policies. Sue has led efforts to develop and adopt standards for charging systems, funding for electric vehicle and infrastructure incentives, public education programs, and a training program for emergency responders.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
IWC	National Electric Vehicle Infrastructure Working Council
NEC®	National Electrical Codes®
NEMA	National Electrical Manufacturer's Association
NFPA	National Fire Protection Association, Inc.
UL	Underwriters Laboratories, Inc. ®

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