ELECTRIC POWER RESEARCH INSTITUTE

Transportation Electrification

A Technology Overview

2011 TECHNICAL REPORT

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A Technology Overview

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Abstract

This report provides a detailed status on the commercial rollout of plug-in vehicles. It describes the key vehicle and infrastructure technologies and outlines a number of potential roles for electric utilities to consider when developing electric transportation readiness plans. These roles have been formulated with the objectives of enabling utilities to demonstrate regional leadership in planning for transportation electrification, to support customer adoption of plug-in vehicles and their supporting charging infrastructure, and to understand and minimize the system impacts from vehicle charging.

Keywords
Charging infrastructure
Electric transportation
Plug-in vehicles
Vehicle charging

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Introduction

A new era of Plug-In Electric Vehicles (PEVs) has begun. Nissan and General Motors have each launched a production plug-in electric vehicle in December, 2010. They will be followed by Ford, Mitsubishi, Toyota, Tesla, and others, all of whom have announced the introduction of plug-in vehicles to the U.S. market by 2011 or 2012. The rapidly approaching commercialization of plug-in hybrid and electric vehicles has created an urgent need for utilities to support the adoption of electric vehicles by their customers, to prepare for the installation of residential, commercial, and private infrastructure in their service territories, and to manage the impact of these new loads on the electric distribution system.

This purpose of this report is to provide a detailed status on commercial rollout of plug-in vehicles, to describe the key vehicle and infrastructure technologies, and to outline a number of potential roles for electric utilities to consider when developing electric transportation readiness plans. These roles have been formulated with the objective of enabling utilities to demonstrate regional leadership in planning for transportation electrification, to support customer adoption of plug-in vehicles and supporting charging infrastructure, and to understand and minimize the system impacts from vehicle charging.

Market Status of Plug-In Electric Vehicles

Plug-In Electric Vehicle Technologies

Plug-in electric vehicles are a family of electric-drive vehicles[1] with the capability to recharge using grid electricity. PEVs generally include battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). A BEV's sole source of energy is the electricity contained in the battery system and must be recharged when depleted to continue operating the vehicle. A PHEV adds a combustion engine to allow extended driving even with a fully depleted battery. One type of PHEV, the Extended Range Electric Vehicle (EREV), operates in similar fashion to a BEV, fully using battery energy before switching to hybrid operation where gasoline is the primary source of energy.

Commercial Availability of Plug-In Vehicles

Large scale commercial production of plug-in vehicles has only just begun in the United States. Prior to the commercial release of the Chevrolet Volt and Nissan Leaf, there were only a few thousand highway-capable electric vehicles in the United States. This existing fleet includes legacy electric vehicles from the 1990s, limited production Tesla Roadsters and BMW Mini-E electric vehicles, aftermarket conversions of hybrid vehicles to plug-in hybrids, and homebuilt or recreational electric vehicles. The first mass produced consumer vehicles began delivery in December 2010—the Chevrolet Volt extended range electric vehicle (a type of plug-in hybrid) and the Nissan Leaf battery electric vehicle. As of May 31st, 2011, Chevrolet had delivered 2,510 Volts and Nissan 2,186 Leafs.[2] Introduction of plug-in vehicles into automotive product lines will likely happen relatively quickly as most major manufacturers have announced production plans for one or more vehicle models.

For medium and heavy-duty commercial vehicles, there are a number of development and limited production programs building light, medium, and heavy-duty commercial fleet vehicles for on-road use. These include delivery vans, small and large transit buses, utility service vehicles, and urban delivery trucks. Non-road electric transportation—which includes electric lift trucks and material handling equipment, airport ground support equipment, truckstop electrification, port electrification, and mining and overland conveyors—has

[1] The term electric-drive vehicle can be used describe any vehicle where the propulsion system contains one or more electric motors that contribute, partly or entirely, toward providing the motive force to drive the vehicle. The family of electric drive vehicles includes electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, and fuel cell electric vehicles.

[2] http://www.hybridcars.com/hybrid-clean-diesel-sales-dashboard

a large inventory of available products that are generally cost competitive with internal combustion equipment at significantly lower greenhouse gas and criteria emissions.

Charging Infrastructure

Charging infrastructure is a crucial aspect of PEV operation. Virtually all PEVs require at least one readily available EVSE at their 'home' parking location—at a residence, parking facility, fleet yard, etc. Residential EVSE infrastructure is the highest priority—national travel survey data shows that vehicles spend 66% of their time parked at home. Employer-provided workplace is also important as vehicles spend 14% of their time parked at work. A public infrastructure is required to provide for the safe recharge and reliable operation of battery electric vehicles. Public infrastructure also increases the electric utility of plug-in hybrids, allowing them to travel greater distances on electricity.

Overview of Charging Equipment

There are a number of different ways to recharge PEVs at power levels ranging from less than one kilowatt (kW) to as much as 250 kW at charging times of less than 30 minutes to more than 24 hours. Most residential and public charging will occur at power levels ranging from less than 1 kW to as much as 19.2 kW and full charge times of 3 – 8 hours. Charging is grouped into two classifications based whether the electricity delivered to the charge port on the vehicle is alternating current (AC) or direct current (DC). With AC charging, an on-board charger (an AC-DC converter) transforms the supply into DC electricity for storage in the battery. In all cases control systems on board the vehicle have ultimate control over the charging process.

AC charging is governed by SAE Recommended Practice J1772 (SAE J1772). Devices called Electric Vehicle Supply Equipment (EVSE) are used to safely control the delivery of AC electricity to the vehicle. There are currently two classifications, referred to as levels for AC charging in North America. Level 1 charging delivers 120 volts AC (VAC) and the EVSE generally consists of a self-contained cordset that terminates in a standard NEMA 5-15R plug compatible with any standard 120 volt household outlet. Level 2 charging delivers 208 – 240 VAC and requires a permanently connected EVSE. The EVSE is typically hard-mounted, either to a wall or a pedestal and supplied by a dedicated circuit. Both Level 1 and Level 2 charging utilize the same connector design at the vehicle and most vehicles can charge at either voltage through the same charge port. Level 1 AC charging is generally limited to 1.44 kW. Level 2 can reach 19.2 kW, with most vehicles and installations using a more modest 3.3 – 6.6 kW.

DC charging, often referred to as 'fast charging,' uses an off-board charging station to convert AC electricity to DC and directly charge the vehicle battery without the need for an onboard charger. Its primary purpose is to enable the rapid recharge of battery electric vehicles. The maximum charging power for a vehicle depends on the battery chemistry and system design. BEVs have already been designed and tested for DC charging at rates of 50 – 60 kW.

Infrastructure Costs

The initial installation of an EVSE can be a significant cost of PEV ownership. Current costs for Level 2 EVSE equipment range from just under $500 to several thousand dollars, depending on the design and capabilities of the equipment. Costs are declining rapidly and most manufacturers indicate near-term availability of Level 2 EVSE at unit prices approaching $1000. Historical installation data indicates that a typical residential EVSE installation will cost approximately $1,500. Commercial installation cost estimates vary considerably, from $2,500 to $6,000 per EVSE. Installation costs are also likely to decrease as familiarity with the charging infrastructure improves.

Infrastructure Ownership Models

Outside personally owned residential charging infrastructure (a home EVSE) there are roughly five models of ownership for charging infrastructure:

1. Municipally owned and operated for public benefit, similar to traffic signals, street lights, etc. Supported through municipal budgets.
2. Utility owned and operated for public benefit. Supported in the utility rate base.
3. Employer owned and operated as an employee benefit

4. Privately owned primarily to enhance an unrelated business—retail shopping, hotels, restaurants, private parking facilities, etc.
5. Privately owned and operated for the sole purpose of providing charging services to PEV owners.

Plug-In Electric Vehicle Adoption Forecasting – Energy and Climate Impacts

PEV Market Adoption Forecasting

Attempting to forecast the rate of adoption of PEVs is a difficult, highly uncertain task. It is also a necessary step towards understanding and preparing for the grid impacts of PEV charging, estimating the positive energy, climate, and other environmental benefits, and planning infrastructure.

EPRI has developed a PEV adoption model consisting of two primary components, preliminary PEV adoption scenarios out to 2030 and a regional (county-specific) model based on vehicle miles traveled (VMT) data. This model enables forecasting of the impacts if PEV adoption at the county, state, or national level. It is important to note that our understanding of rate of PEV adoption will change frequently as this new market developed—therefore PEV adoption scenarios must also change continually to reflect new information as it becomes available.

EPRI developed three scenarios to forecast the impacts of low, medium, and high projected rates of PEV adoption between 2010 and 2030. The low scenario is primarily patterned after HEV sales performance from 2000 to 2008 and predicts total PEV sales in the United States of 600,000 vehicles in 2015, 3.1 million by 2020, and slightly fewer than 15 million by 2030. The medium scenario is based on HEV sales combined with announced manufacturer plans for PEV models and production volume. The medium scenario projects 1.2 million PEVs by 2015, 5.8 million by 2020, and nearly 35 million by 2030. The high scenario is an optimistic view of PEV adoptions and forecasts 2.4 million PEVs by 2015, 12 million by 2020, and over 65 million by 2030. Regardless of scenario, the electrification of the passenger vehicle fleet in the U.S. is a long-term event.

As an example of regionally specific analyses, the results for several states are included in the report.

Energy and Climate Impacts of PEV Adoption

The results of PEV adoption forecasting can be used to also project energy and climate impacts. This report shows electricity consumption, gasoline savings, and CO_2 reduction for each of the adoption scenarios. The regional nature of this model allows for the incorporation of regionally specific data or forecasts for the environmental, energy, or economic characteristics of electricity, gasoline, and other fuels.

For the medium scenario, electricity consumption from PEV adoption is forecasted at 4.4 terawatt-hours (TWh) in 2015, rising to 16 TWh in 2020 and nearly 80 TWh in 2030. This electricity displaces about 380 million gallons of gasoline in 2015, 1.4 billion in 2020 and 7.0 billion in 2030. CO_2 emissions decrease due to this net change in energy consumption—electricity is a lower carbon transportation fuel than gasoline. The net reduction is 2.1 million metric tons in 2015 and increases by approximately 2 million metric tons per year, to nearly 48 million metric tons per year in 2030.

Grid Impacts of Plug-In Electric Vehicles

The charging of PEVs has the potential for both positive and negative impacts to the electric grid. Understanding and addressing potential PEV impacts to the electric grid is a critical role for the electric utility and a key enabler of both widespread PEV adoption and maximizing the benefits of transportation electrification.

PEV Charging Patterns and Load Shapes

The timing of PEV charging is a key determining factor of the grid impacts. It is important to understand the statistical driving patterns that are likely to impact charging behavior. This includes both the time a vehicle arrives home and the distance it drove, which will govern its total electricity demand. For residential charging, the general case is that a PEV will begin charging after is arrives at home and is plugged in. National Personal Transportation Survey (NPTS) data indicates that the peak arrival time is 5-6 pm, however only about 12% of vehicles arrive home during this hour, leading to a distribution of charging onset times.

This results in an effective peak charging load of about 700 watts per vehicle. So while residential charging power levels vary from about 1.4 to 7.7 kW, the average impact of a single vehicle on the electric system is far lower.

There are significant efforts underway to alter the load shape generated by PEV charging, whether by use of electricity pricing incentives, actively managed or 'smart' charging, or onboard programming of charging times. These would have the effect of moving the load off the peak. In an ideal scenario, charging for many PEVs could be delayed until after 9 pm with the expectation that every vehicle must be completely charged by the early morning. In this case, the per vehicle electricity demand is still about 700 watts per vehicle, only it is now relatively steady from about 11 pm to 3 am. So while the demand is roughly the same, it now occurs at a time of much lower total electricity demand.

Evaluation of PEV Distribution System Impacts

At a system level, due to diversity, the electricity demand of PEVs is relatively low, likely resulting in minimal impacts to utility generation and transmission assets, particularly in the near term. At the distribution level, there are numerous transformers and other assets that are designed to serve only a small number of customers. These assets benefit far less from diversity and should receive greater study and analysis as to how they might be impacted by PEV charging. This is a normal part of the utility distribution planning process.

EPRI has conducted numerous detailed and sophisticated studies of the distribution system impacts of PEV charging to enable utilities to understand the impacts of this new load on their systems and to augment their planning processes for the additional demand on their systems.

While there are many different distribution systems design practices among utilities and each distribution circuit is different some conclusions of this analysis are:

- Diversity of vehicle location, charging time, and energy demand will minimize the impact to utility distribution systems
- Level 1 charging generates the fewest distribution system impacts
- Higher power Level 2 charging generates the strongest system impacts and is typically not required for most customer charging scenarios
- Short-term PEV impacts for most utility distribution systems are likely minimal and localized to smaller transformers and other devices where the available capacity per customer is already low
- Controlled or managed charging can defer system impacts for a significant period of time

EPRI believes that potential stresses on the electric grid can be fully mitigated through asset management, system design practices, and at some point, managed charging of PEVs to shift a significant of load away from system peak. A proactive utility approach of understanding where PEVs are appearing in their system, addressing near-term localized impacts, and developing both customer programs and technologies for managing long-term charging loads is most likely to effectively and efficiently enable even very large-scale PEV adoption.

Electricity Pricing for Plug-In Vehicles

Electricity is a low-cost transportation fuel that has been historically stable in its pricing relative to gasoline. At current U.S. gasoline prices and average electricity rates, plug-in vehicles can be driven for roughly one-third to one-fourth the cost of a gasoline-powered vehicle. Time-of-use (TOU) electricity pricing is generally seen as an effective way to provide an economic incentive for PEV drivers to charge during off-peak hours, minimizing the cost of electricity and reducing stress on the grid—with the limitation that electricity is so much less expensive than gasoline in most areas that PEV drivers may still choose to charge at peak electricity rates to ensure their vehicle is sufficiently charged. Some consumer research indicates that consumers are generally receptive to the idea of off-peak charging given a reasonable economic incentive.

Potential Roles for the Electric Utility

There are number of potential roles for an electric utility that can support the commercial introduction of electric vehicles, increase customer adoption, provide support to utility customers, and minimize adverse impacts to the electric grid. Each role described in this report must be considered for its overall feasibility given the utility's specific objectives and regulatory requirements. These include:

1. Customer outreach and education. The utility leverages its relationship with its customers to educate them and create awareness of the different plug-in vehicle technologies and related charging infrastructure.
2. Development of critical infrastructure and services to support the safe and secure operation of electric vehicles throughout a utility's service territory.
3. Facilitate the implementation of residential, commercial, and public charging infrastructure throughout a utility service territory.
4. Understand and mitigate potential system impacts—specifically to the distribution system—by analyzing its distribution system and understanding likely rates of PEV adoption and geographic clustering.
5. Adopt plug-in vehicles within the utility fleet and install supporting infrastructure.
6. Conduct an active research, development, and demonstration program to acquire useful knowledge and data of the real-world operation of PEVs and to contribute to and understand the development of new technologies

Section 2: Market Status of Plug-In Electric Vehicles

With increasing constraints on conventional vehicles and their energy supply chains, the further electrification of personal and commercial vehicles offers promising alternatives for enabling transport and mobility. From on-road passengers to heavy duty equipment, vehicle electrification can provide options with measurable benefit and near-term market potential in a growing number of applications. This section provides an overview of near-term market developments, production plans, and incentive programs for plug-in electric vehicle (PEV) development.

Passenger Vehicle PEV Development

Media related to PEV technology tends to emphasize passenger vehicle development, often in the form of manufacturer announcements. Within the last year, nearly every major auto manufacturer has announced their intention to market PEVs in one form or another. Some have opted to build upon their existing hybrid electric vehicle (HEV) platforms, while others are choosing to introduce entirely new product lines. Whatever the approach, it now appears obvious that personal vehicle electrification is an industry-wide trend and a growing consumer priority. What remains uncertain is not whether PEVs will be made available for purchase in the near-term, but rather when, where, and at what cost PEVs will enter the market.

Prior to the December 2010 launch of the Volt and the Leaf, the only available PEV offerings from manufacturers with a commercial presence in the U.S. market were BMW and Tesla. BMW produced roughly 600 Mini-E electric vehicles for customer pilot programs in the U.S. and E.U. These vehicles were developed with powertrain technology from AC Propulsion, a small firm in Southern California with a long history of pioneering EV technology. These vehicles were only available for short-term lease from BMW. Tesla has developed the Roadster, a high-performance battery electric two-seat sports car also produced in limited volume (current sales of between 1500 – 2000 vehicles) with retail prices exceeding $100,000 each. A handful of Scion x-B conversions (e-Boxes) have been produced and sold by AC Propulsion directly for about $75,000.

Battery Electric Vehicles

The Nissan Leaf (Figure 2-1) was the first mass-produced battery electric vehicle in the U.S. market. Released in very small numbers in December, 2010, Nissan has delivered 2,186 Leafs to the U.S. through May 31, 2011. The Leaf has a 24 kWh Lithium Ion (Li Ion) battery system that provides and EPA-rated range of 73 miles. The Leaf charges from 'empty' in less than eight hours using a dedicated 240-volt charging station (3.3 kW charge rate). The Leaf has an optional DC 'fast' charging port that charge the vehicle in roughly 30 minutes from a dedicated DC charge station.

Mitsubishi has been selling their i-MiEV battery electric vehicle in Japan since late 2009. Mitsubishi has announced they will release a lefthand drive version of the i-MiEV—renamed the Mitsubishi 'i' (Figure 2-1) in the United States in late 2011. The 'i' has a 16 kWh Li Ion battery and has both conventional and fast charge capability

Figure 2-1
Nissan Leaf battery electric vehicle, Photo courtesy of Nissan

Figure 2-2
Mitsubishi intends to launch the U.S. version of the iMiEV, now called the 'i' in late 2011. Photo courtesy of Mitsubishi

Ford is also readying its Focus Electric vehicle (Figure 2-3) for launch in late 2011. The Focus Electric has a 23 kWh battery system and charges at twice the rate of current production vehicles—6.6 kW.

Tesla, until recently the highest volume passenger PEV producer with over 1500 Tesla Roadsters delivered, is developing the Tesla Model S, a large, high-performance luxury sedan with very high range (Figure 2-4). When it is released in late mid-2012, it is expected to be one of, if not the largest electric vehicle on the market. It is also likely the first vehicle with optional battery pack sizes, with announced range options of 160, 230, and 300 miles.

Figure 2-3
Ford Focus Electric battery electric vehicle. Photo courtesy of Ford.

Figure 2-4
Tesla Model S large battery electric luxury sedan. Photo courtesy of Tesla.

There are numerous battery electric vehicles announced by other manufacturers.

Plug-In Hybrid Electric Vehicles

Plug-in hybrid electric vehicles are distinguished from battery electric vehicles by adding a combustion engine to the system to enable the vehicle to continue driving once the battery is depleted. The foundational principle of a PHEV is to size the battery to account for daily driving and to use the engine for longer trips. Unlike a BEV, the PHEV does not need to carry additional 'extra' battery around for unexpected trips. This adds complexity—however in reducing the size of the battery system, significant cost and weight savings are realized.

The Chevrolet Volt (Figure 2-5) was launched in December 2010. Chevrolet refers to the Volt as an Extended Range Electric Vehicle (EREV) to highlight the fact that the Volt behaves exactly like a BEV for the first 25 to 50 miles of operation after a full charge. Once the battery is depleted, a gasoline engine engages and the vehicle can operate in hybrid mode as long as there is gasoline in the tank.

Figure 2-5
The Chevrolet Volt Extended Range Electric Vehicle (EREV). Photo courtesy of General Motors

While the Volt is the only vehicle of its kind currently available for purchase, other companies are also developing plug-in hybrids. Toyota is developing a plug-in version of the extremely popular Prius hybrid vehicle for sale in mid-2012. In preparation for the launch of its first plug-in vehicle, Toyota has conducted R&D and pilot demonstration programs with approximately 100 Prius hybrids modified for plug-in capability (Figure 2-6). Toyota is also developing a limited production battery electric version of the RAV4 SUV with Tesla.

Ford is also developing a PHEV of similar size and capability to the Prius Plug-In. The C-MAX Energi (Figure 2-7). The C-MAX Energi will likely rely solely on its battery for low speeds and stop-and-go driving. At higher speeds, the battery and engine will work together to power the vehicle.

Figure 2-6
Toyota Prius Plug-In Hybrid Photo courtesy of Toyota

Figure 2-7
Ford C-MAX Energi Plug-In Hybrid. Photo courtesy of Ford.

In addition to passenger vehicle electrification, several companies have announced plans to release commercial utility, fleet, bus, and cargo vehicles for the near-term market. Due to the stop-and-go nature of city driving, taxi and delivery vehicles are exceptionally good candidates for vehicle electrification. Ford has already begun delivering the Transit Connect Electric (Figure 2-8), a small battery electric commercial van developed in partnership with Azure Dynamics. Smith Electric Vehicle has developed a battery electric Class 6 commercial truck with up to 100 miles of range. A few fleets (like Frito Lay, Figure 2-9) have already adopted large numbers of these vehicles for their delivery fleets.

Figure 2-8
Ford Transit Connect Electric. Photo courtesy of Ford

Figure 2-9
Frito Lay's fleet of Smith Electric Vehicle Class 6 battery electric delivery trucks and Level 2 (240 volts) charging infrastructure. Photo courtesy of Clipper Creek.

Non-Road PEV Development

Large opportunities exist for the increased electrification of non-road vehicles and equipment. Non-road electric transportation technologies are helping reduce emissions and fuel consumption in locations off the beaten path – at seaport loading docks, on airport runways and in warehouses and manufacturing plants. This specialized equipment can not only save end use customers money but improve their operating efficiencies and maintenance programs as well.

Non-road electric transportation includes an array of applications delivering substantial benefits today to electric utilities, their customers, and the environment. Yet many applications remain untapped, and many utilities and their customers remain unaware of the potential. Electricity is a cheaper transportation fuel than petroleum and the electrification of non-road transportation systems that move materials, cargo, and people can help electric utilities increase revenues and manage load. They also help end-use customers reduce pollutant and greenhouse gas emissions, save money on fuel, and in many cases improve operational efficiency and productivity.

Since 1994 EPRI's Non-Road Electric Transportation program has performed technology demonstrations, developed case studies and information to communicate benefits to utilities and their customers, and participated in developing standards to ensure the interoperability and safety of electrical connections and charging infrastructure. EPRI facilitates technology transfer by hosting meetings where utility staff, regulators, and industry experts discuss the latest research and demonstration successes, challenges, and opportunities. The program has focused on four key segments: seaports, airports, industrial material handling, and truck stop electrification.

Seaports

Seaports are major economic hubs and are often the top sources of air pollutants— including NOx, SOx, volatile organic compounds, and particulate matter—that contribute to adverse air quality, as well as greenhouse gases. As a result, seaports across the nation face increasing pressures to reduce emissions and improve efficiency as they increase throughput and expand operations to accommodate growing global trade. Many ports are finding that replacing fossil-fueled equipment with electric alternatives is a feasible and successful strategy. In addition to electrifying cargo-handling equipment such as yard tractors, seaports offer other opportunities for electrification, including shore power, electric dredging, and electric cranes.

Shore power

Traditionally, cargo and passenger ships docked in port have used auxiliary diesel generators to run the ship's lighting, refrigeration, heating, and air conditioning systems. These engines consume considerable fuel and account for a significant fraction of port emissions. Shore power, also known as cold ironing, allows berthed ships to shut down their diesel generators and instead plug into dockside electric service to power onboard systems. Shore power effectively eliminates at berth emissions and fuel consumption and opens new business opportunities, as demonstrated by a shore power collaboration involving Seattle City Light, the Port of Seattle, the U.S. EPA, and the Holland America and Princess cruise ship lines. As documented in an EPRI case study (1013879), the Seattle shore power operations reduced NOx emissions by more than one ton per ship per day, saved 12.5 tons of fuel per call, and slashed annual CO2 emissions by 3,525 tons. Ships using shore power consumed about 5 to 11 megawatthours (MWh) of electricity per port call. As with other transportation applications, shore power opens opportunities for emissions trading. Seattle City Light purchases $10,000 in greenhouse gas off sets annually from each cruise line. Shore power requires investment in shipboard and landside electrical infrastructure, including cabling, connections, and transformers. Despite the investment, shore power is gaining momentum, stimulated in part by new regulations mandating cold ironing in California ports. However, no standard exists for shore power cable, connectors, or transformers. EPRI, through the Infrastructure Working Council, is supporting standardized infrastructure to reduce costs and ensure interoperability and safety.

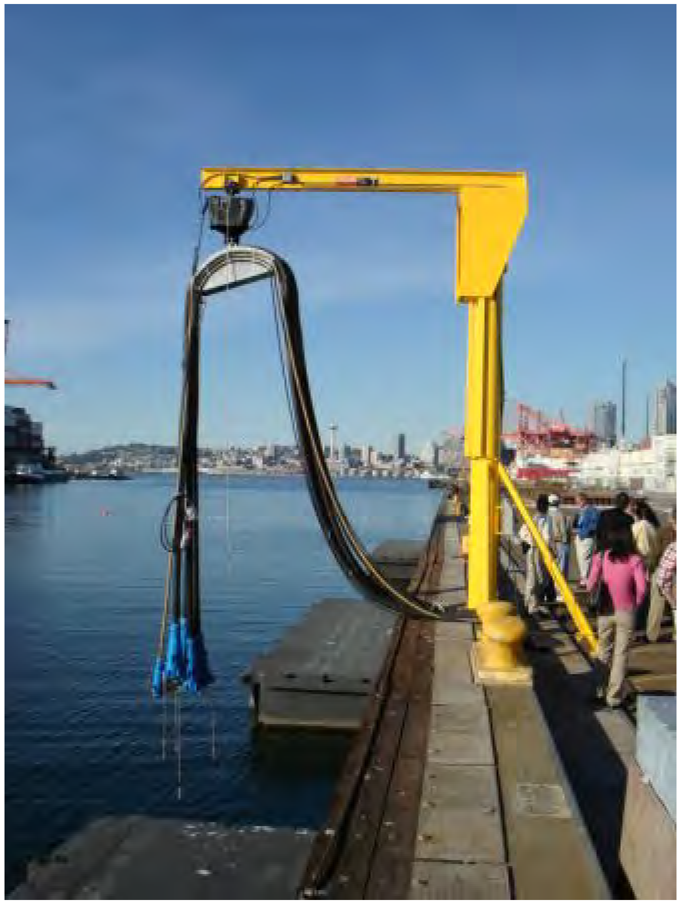

Figure 2-10
Shore power installation in Seattle, WA October 2006. Photo credit: Robert Hawkins

Electric dredging

Most ports perform regular dredging to maintain channel depths suitable for navigation. Dredging using electric motors instead of the standard diesel engines can offer environmental advantages and economic and operating efficiencies, including significant emission reductions and savings in equipment operations and maintenance. As a result, electric dredging is now the norm at ports such as Oakland, Long Beach, Los Angeles, and Houston. The Port of Mobile, Alabama, joined their ranks in 2009. King Fisher Marine's electric dredge the Waymon Boyd recently completed the port's first electric dredge with support from Alabama Power in partnership with EPRI. Using a series of electric pumps and motors, the Waymon Boyd loosens and sucks up mud and sediment, then discharges the material through a system of pipes to a site four miles away. The total electrical load for the dredge was 4.6–4.8 MW, with power delivered from shore via a 3-inch-diameter cable. A 3,000-horsepower diesel engine–powered dredge, similar in size and capability to the Waymon Boyd, would use approximately 2,000 gallons of diesel fuel per day, assuming 24-hour operations, and produce about half a ton of NOx per day and almost 28 tons per day of CO2. To put these emissions into perspective, a ton of NOx per day is equivalent to more than a million passenger vehicle miles, and an average passenger vehicle emits approximately 6 tons of CO2 per year. Noise abatement is another environmental benefit of electric dredging—a particular concern when dredges operate around the clock near neighborhoods. The cost to operate an electric dredge compared to diesel depends on the price of electricity versus diesel. In many places electric dredging brings a distinct economic advantage. Daily fuel costs for a diesel dredge similar in size to the Waymon Boyd consuming 2,000 gallons of fuel per day at $3.00 per gallon would run $6,000. In comparison, an electric dredge drawing 36,510 kWh at Alabama Power commercial rates of approximately 9 cents per kWh would run at $3,286 per day.

Figure 2-11
Waymon Boyd at the Port of Mobile, July 2008. Photo credit Andra Rogers.

Yard Tractor

Diesel-powered terminal tractors are the workhorses of seaports. At major ports hundreds of such tractors operate around the clock, shuttling cargo trailers from point to point in the container terminals. Yet even at the busiest ports, terminal tractors spend up to 80% of their shift with engines idling as they wait to pick up their loads. Such idling results in unnecessary and avoidable emissions, fuel consumption, and expense. In 2007 EPRI began a development program aimed at these tractors, and in 2009, a plug-in hybrid terminal tractor, or sometimes called a yard tractor, was developed. Its engine allows it to travel ten miles or more on electric power and to shut down its diesel engine when idle to reduce emissions and save fuel. The hybrid is the product of an EPRI collaboration with CenterPoint Energy, New York Power Authority, Southern California Edison, and Southern Company. Following a three-month demonstration at Long Beach, the tractor will pull duty in Houston, Savannah and New York. At each port, the project team will collect data on the tractor's performance, including fuel consumption, emissions, service and maintenance, and operator acceptance. Findings will determine if the plug-in hybrid technology is suitable for widespread application at seaports.

Figure 2-12
EPRI PHEV Yard Tractor at the Port of Long Beach, February 2010. Photo credit Jeff Kohne.

Airport Electrification

Airlines face a challenging mix of competitive, regulatory, community, and environmental demands. In response to fuel costs and pressure to reduce emissions, airlines are electrifying equipment traditionally powered by fossil fuels.

Electric ground support equipment

Airport ground support equipment, including baggage tugs, belt loaders, and pushback tractors, is a natural candidate for electrification. Research conducted by the New York Power Authority (NYPA) showed that a single internal combustion–powered tug emits 54 tons of greenhouse gases, burning 3,248 gallons of diesel per year. In 2000 EPRI organized a project to electrify American Airlines' ground support equipment at Detroit Metro Airport. EPRI helped develop specifications for electric connectors to help provide infrastructure and ensure safety and reliability of fast charging. EPRI also helped develop methods to help users weigh the costs and benefits of electric ground support equipment.

Ground power

Aircraft parked at the gate need preconditioned air to ensure cabin comfort and electric power to operate onboard systems. Traditionally the air and power have been delivered through an auxiliary power unit, a small jet-fueled turbine in the back of the aircraft. Alternative power sources include a diesel generator on the ground or solid-state converters connected to the airport's main power. An EPRI case study documents Southwest Airlines' procedures to minimize use of the auxiliary unit, saving fuel and money and reducing emissions. Southwest has electrified its gate operations in almost every city it serves. Southwest estimates average fuel savings of 12 to 17 gallons for every turn at the gate. (A turn is estimated at 20 to 30 minutes. The average auxiliary power unit burns 34 gallons per hour under a normal load and up to 42 gallons per hour under a heavy load.) At 3,300 flights per day, the daily fuel savings can be as much as 56,100 gallons. Annual fuel savings are as much as 20,476,500 gallons. Fuel prices have varied dramatically recently, but even at a hedged price of approximately $1.80 a gallon, the savings are significant: $36,857,700.

Figure 2-13
Hose delivering 400 hertz ground power to the airplane. Photo credit: J Knapp Communication

Material Handling

In warehouses, manufacturing plants, and distribution centers, electric forklifts, cranes, and side loaders are boosting utility revenue while helping industrial customers reduce fuel and maintenance costs. Over the past 25 years, sales of electric forklifts (or lift trucks) have grown from less than one-third to more than half of annual lift truck sales. Most have been limited to indoor use, but several manufacturers now add features such as pneumatic tires and enclosed battery compartments that enable use outdoors. A recent EPRI–Southern Company–NYPA project demonstrated outdoor-capable forklifts to industrial customers, most of whom were unaware that such were available, even though they're widely used in Europe. Based on EPRI technical data, Alabama Power's forklift incentive program has contributed millions of dollars to the utility's bottom line, as customers convert forklift fleets to electric power or add to existing electric fleets. While building load isn't every utility's goal, increasing efficiency is. For some utilities, shifting load is even more important. In 2002, Southern California Edison launched an electric forklift peak-load shifting program in response to the California energy crisis. Through state-provided incentives and time-of-use rates, SCE encouraged customers to shift battery charging off -peak, ultimately shifting 9,100 kW, 14% over its goal.

Encouraging the use of electric material handling systems also helps utilities forge strong, mutually beneficial relationships with customers due to higher earnings and saving money by reducing fuel and maintenance costs and improving efficiency. Additionally, the environmental attributes and being seen as green partners within their communities. And they want to be sure their employees have a safer and cleaner work environment. Electric technologies score touchdowns in all these areas. Electric equipment not only helps reduce emissions, but also minimizes maintenance, repairs, and equipment downtime because electric motor technology is more efficient and produces less wear and tear than internal combustion engines. There is less heat and vibration generated in comparison to internal combustion systems, and fewer moving parts.

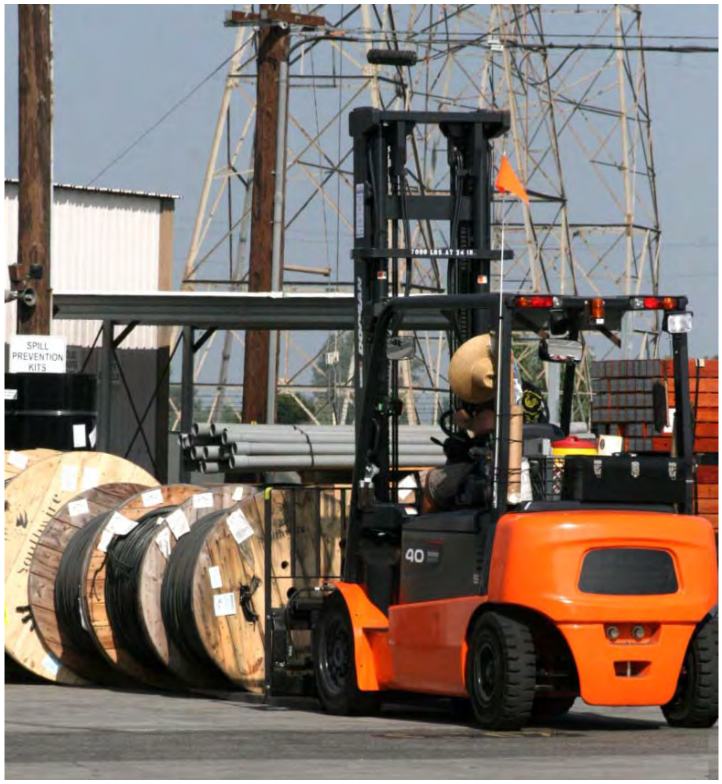

Figure 2-14
Outdoor electric lift truck. Photo credit: Brian Jones.

Truck Stop Electrification and Idle Reduction

Like ships in port, long haul trucks, or big rigs, parked at truck stops sit with engines idling to provide electricity to protect refrigerated cargo and power air conditioning, heating, and appliances for drivers in truck cabs and sleeping berths. Idling engines consume more than a gallon of fuel per hour, and each of the 1.3 million long-haul trucks in the United States consumes about 2,400 gallons or more per year while idling. New technologies enable drivers instead to rely on battery storage or electrical connections.

Of approximately 5,000 truck stops in the United States, about 136 are equipped with electrified parking spaces, according to the U.S. DOE Alternative Fuels and Advanced Vehicles Data Center. Electrified parking spaces are available in 34 states.

The term Truck Stop Electrification can mean several things. Because the industry is relatively young, different technologies are being used and demonstrated across the country. There are two main electrification technologies that can enable a truck driver to avoid idling.

Off-board systems

Off-board systems, sometimes called stationary systems, are permanently installed at truck stops. They can be designed so that no special equipment is needed on the truck. A trucker simply pulls into a designated parking spot, reaches out to an air hose and control module hanging from an overhead gantry, and inserts them into a special window template. An alternative off-board system design may require some equipment on the truck as well as on the ground. With off-board systems, the truck stop owner makes the capital investment and recoups its investment by selling services—electricity, Internet, entertainment—to the trucker.

On-board systems

On-board systems, sometimes called mobile technologies, are installed on the truck. They generally comprise an inverter to convert 120-volt power, an electrical HVAC system, and the hardware to plug into "shore power" electrical outlets at truck stops. Some on-board systems use batteries that can either be charged by the main engine during driving, or plugged in during stops. With on-board systems, the truck owner makes the capital investment and maintains the equipment. The perceived advantage is that a driver can stop and use his or her system anywhere there is shore power.

Figure 2-15
Shorepower Technologies 120-volt charge stations which utilize an on-board system

Untapped Potential

EPRI and utility organizations are pursuing additional opportunities in non-road electric transportation. Southern Company is evaluating underground mines' material handling equipment that relies on internal combustion engines. Southern is also working with customers to implement electric overland conveyors to transport materials over distances of a few hundred yards to several miles, replacing loading and unloading now done by internal combustion vehicles. In addition, hybrid and battery powered locomotives are being developed for the cargo rail industry, while passenger rail is far ahead with 50% of rail being electrified. Agriculture and Construction industries are also taking notice, as hybrid tractors are in development.

Table 2-1
Table: Non-road Electric Transportation with Electrification Options

Equipment	Primary Industry	Primary Fuel
Ships (Crude oil tankers and Container Ships)	Seaport	Residual Fuel
Cargo Handling Equipment (Yard Tractors)	Seaport, Warehouse	Diesel
Cranes (Ship to Shore and Rubber Tired Gantry)	Seaport, Intermodal/Rail	Diesel
Dredge	Seaport	Diesel
Forklifts	Warehouse	Diesel, Liquid Propane Gas, Electric
Mining equipment (Shuttle Cars, Ram Cars, Haulage Systems, Draglines and Electric Shovels)	Mining	Diesel
Overland Conveyer	Mining	Diesel
Locomotives	Rail	Diesel
Passenger Rail	Rail	Diesel
Tugboats	Seaport	Diesel
Farm Tractors	Agriculture	Diesel
Ground Support Equipment	Airport	Diesel
Aircraft Ground Power	Airport	Diesel
Lawn and Garden	Agriculture	Gasoline
All-Terrain Vehicles	Agriculture	Gasoline
Truck Refrigeration Units	Trucking	Diesel
Long Haul Trucks (idling)	Trucking	Diesel

Portions of this section are derived from EPRI Journal Summer 2009 article titled “Electric Transportation, Beyond the Road” written by David Boutacoff.

PEV Component Development

Two components that are likely to have a significant effect on the penetration rate of PEV technology are batteries and power electronics, with greater cost sensitivity relative to conventional vehicle technologies. Lithium ion battery chemistries are likely to dominate PEV markets for some time, with competitive manufacturing currently under way worldwide. GM has claimed that their battery pack cost will be between $600 and $700 per kWh for their first round of Volt development and is expected to drop significantly with greater production volumes. Battery performance has been improving steadily, a fact that can be observed by the full shift in commitment to Li-ion chemistries and increasing commitments to PEV development in general (e.g. Toyota speeding their release of the Prius PHEV).

Power electronics control the flow of energy into and out of the PEV battery. This could include on-board or off-board chargers and on-board power conditioning (e.g. power inversion for use by the electric motor). While power electronics will represent a significant up-front cost for PEV development in the near-term, cost is expected to decrease considerably with volume and with electrification trends in general. Ideally, the cost of power electronics will follow similar trends to those observed in the personal computing market. Fast charging could add significantly to this cost, though it is still unclear whether fast charging will be required to enable PEV adoption.

PEV Technology Demonstrations

Recent economic stimulus funding distributed by the U.S. federal government is providing new incentives for growing the electric vehicle market. As part of the American Recovery and Reinvestment Act of 2009, two billion dollars were allocated for battery research and early manufacturing. In total, $2.4 billion were awarded as grants to 48 projects with organizations representing cell, battery, and materials manufacturing; advanced battery systems manufacturing; battery recycling, refurbishing, and reuse; drivetrain component and vehicle manufacturing; in-home and public charging deployment; and electric vehicle technology education (Figure 2-16). The largest recipients of stimulus funding were General Motors (GM) and their battery developers LG Chem, who received a total of more than $390m (~ $240m and $150m, respectively). Additional incentives at the state level include a $355 million tax credit offered to companies willing to develop batteries in Michigan (e.g. JC-Saft awarded $148M). Though the $2.4 billion for advanced vehicle development makes up only ~ 0.3 % of the full federal stimulus package, it represents a significant public investment relative to historical R&D spending for energy technology, particularly since the money has been directed primarily toward technologies closely related to advanced batteries, vehicles, and charging units.

In addition to funding for battery development and demonstration, stimulus money provided under FOA-28 has been directed primarily toward near-term technology demonstrations with an emphasis on vehicles and charging infrastructure (Table 2-2). The largest award granted under FOA-28 went to ETEC, a subsidiary of ECOtality. ECOtality will demonstrate approximately 12,500 Level 2 chargers and 250 DC fast charging units, while Nissan will supply 5,000 BEVs with approximately 100 miles of electric driving range (e.g. the Leaf). Known as the 'EV Project' this award originally targeted areas within five states—California (San Diego), Arizona, Tennessee, Oregon and Washington. The program has been expanded to include cities in Texas, Washington, D.C., and Los Angeles as well as adding the Chevrolet Volt. The total FOA-28 funding allocated to ECOtality and Nissan is nearly $130 million.

A second major infrastructure demonstration funded from FOA-28 is ChargePoint America, awarded to Coulomb Technologies. This program installs and monitors charging infrastructure in several states in the U.S., including Massachusetts (Boston), California (Sacramento, San Francisco Bay Area, Los Angeles), Texas (Austin), Washington (Bellevue/Redmond), Florida (Orlando/Tampa), New York (New York City), Washington D.C., Maryland (Baltimore), and Michigan (Lansing, Ann Arbor, Grand Rapids, Detroit). This program is co-funded the California Energy Commission.

Chrysler was awarded $70m under FOA-28 to develop PHEV pickups. SCAQMD, in cooperation with EPRI has been awarded $45m to demonstrate up to 378 PHEV trucks and shuttle buses (Class 4 – 5). This project builds upon prior experience with the PHEV Trouble Truck program (Figure 2-17), greatly expanding fleet size and data collection capabilities. GM was awarded $30m for its demonstration of 125 fleet EREVs (i.e. the Volt) and 500 in-home consumer EREVs.

In addition to those demonstrations funded under FOA-28, BMW and Toyota are also moving forward with significant vehicle demonstration programs of their own. BMW has provided 500 electric Mini Coopers (Mini-E) to consumers for short-term lease through 2011, while Toyota is demonstrating several hundred Prius PHEVs in Europe and the U.S. Daimler conducted a similar demonstration of a battery electric version of the Smart city car. Each of these demonstration programs is expected to lead to a production plug-in vehicle. BMW has announced a new demonstration with the Active-E, a battery electric version of the 1-Series sedan, followed by the 'Megacities' production electric vehicle in 2013 or 2014. Toyota has announced the production Prius Plug-In for 2012. Limited volume sales of the Smart ED began in 2011 in the U.S.

To complement production development and demonstration incentives, there are also consumer incentives available at both the state and federal levels for PEVs and aftermarket conversions. A federal tax credit of between $2,500 and $7,500 is available to consumers purchasing vehicles (GVW < 14,000 lbs) with at least 4 kWh of battery storage. The amount is based on the size fo the vehicle's onboard energy storage system, starting at $2,500 for 4 kWh plus $417 per additional kWh of storage, up to a total of $7,500. Each manufacturer has a cumulative cap of 200,000 vehicles whose owners are eligible for the credit.

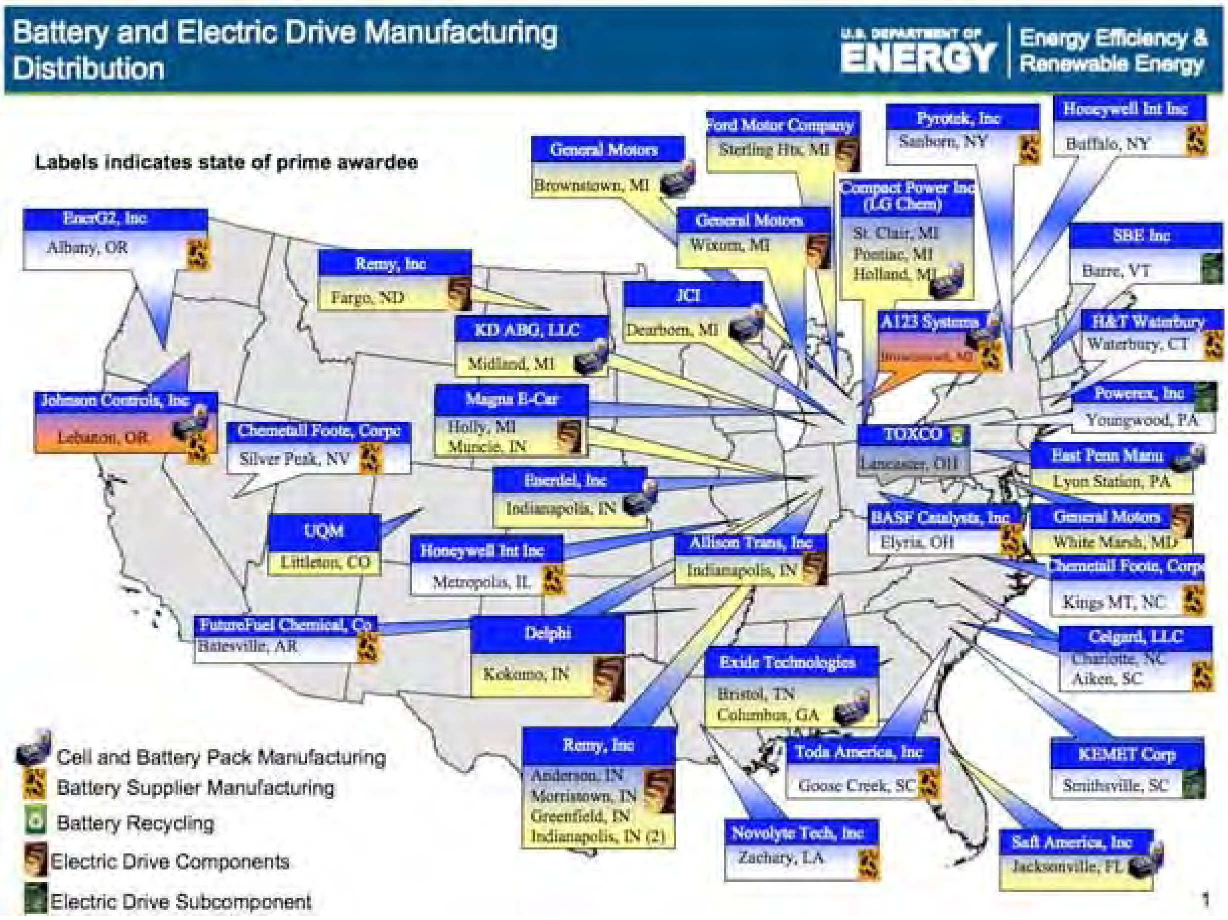

Figure 2-16
Recipients of stimulus funding for batteries and PEV-related technology.

Table 2-2
Some of the recipients of federal stimulus funding provided under FOA-28 for advanced vehicle electrification.

Advanced Vehicle Electrification + Transportation Sector Electrification		
Electric Transportation Eng. Corp. (ECOtality)	$99.8	ECOtality and its partner Nissan will demonstrate up to 5,000 Nissan electric vehicles with a 100 mile range and deploy up to 12,500 Level 2 and 250 Level 3 chargers.
Chrysler LLC	$70.0	Develop, validate, and deploy 220 advanced plug-in hybrid electric pickups and minivans.
South Coast AQMD (EPRI, Eaton, Altec, Ford, SCE, Utilities)	$45.4	Develop a fully integrated, production plug-in hybrid system for Class 2 – 5 vehicles (8,501 – 19,500 lbs gross vehicle weight). Demonstrate a fleet of 378 trucks and shuttle buses.
General Motors	$30.5	Develop, analyze, and demonstrate hundreds of Chevrolet Volt Extended Range Electric Vehicles (EREVs) –125 Volt PHEVs for electric utilities and 500 Volt PHEVs to consumers.

Figure 2-17
President Obama looks over the PHEV Trouble Truck during a visit to Southern California Edison. Photo courtesy of SCE.

Section 3: Charging Infrastructure

Overview of PEV Charging

Electric vehicle manufacturers and charging equipment suppliers follow standards for the recharging of plug-in vehicles. These standards were developed to enable the maximum level of intercompatibility between plug-in vehicles and charging infrastructure.

There are two methods to charge PEVs:

- AC charging – alternating current (AC) is supplied to a receptacle on-board the vehicle where the on-board charging system converts it to charge the battery. The supply of electricity to the vehicle is controlled by an off-board device called an Electric Vehicle Supply Equipment (EVSE)
- DC charging – a high capacity AC electrical supply is converted to direct current (DC) off-board the vehicle by a charging station and delivered directly to the vehicle's battery

All commercially available PEVs have the capability for AC charging and this is widely seen as the dominant form of vehicle charging. DC charging (also known as 'fast charging' or 'quick charging') is used for higher rate, faster charging applications. Not all vehicles have DC charging capability.

All commercially available PEVs now use a conductive connector to transfer alternating current (AC) electrical energy to the vehicle's battery system. Charging takes place when there is a physical connection between the electric source and the charger circuitry onboard the PEV through a connector. This connector is commonly referred to as the 'J1772' connector, after the name of the Society of Automotive Engineers (SAE) recommended practice (J1772) specifying the connector, receptacle, and associated charging circuitry.

PEV Charging Levels

Electric vehicle charging is performed at different voltage levels and using different technologies depending on the model of the PEV and the type of charging situation. Level 1 and Level 2 PEV charging are the most common and are found in most charging station installations, while DC 'fast' charging is most often associated with operations in fueling station or commercial fleet environments.

PEV manufacturers may have adopted Level 1, Level 2, and even DC charge capabilities. Nissan and Mitsubishi have incorporated both AC and DC charging capabilities on their Battery EV models, and provide connectors for both Level 1 and Level 2 charging with the purchase of the vehicle. Consumers must check with the manufacturer concerning the charging specifications for individual car makes and models.

Table 3-1
Characteristics of Level 1 and Level 2 PEV Charging

	Voltage	Amps	Power (kVA)	Phase	Supply Connection	Charge Time (average)
Level 1	120	12	1.44	single	NEMA 5-15R	3-10 hrs.
Level 2	208/240	12 - 80	19.2	single	Hardwired[3]	3-8 hrs.

[3] The National Electric Code appears to define scenarios where Level 2 EVSEs can be cord-and-plug connected. This has caused some EVSE manufacturers to offer this feature on Level 2 EVSE products. Not all stakeholders agree on this issue and interpretation of the relevant portions of National Electric Code will likely vary between jurisdictions.

Level 1 AC Charging

Level 1 AC charging uses a standard 120-volt, single-phase, three-prong grounded electrical outlet (NEMA 5-15R) to charge a PEV. Level 1 charging outlets should have ground fault interrupts (GFI) installed and 15 amps minimum branch circuit protection. A dedicated circuit is not required but recommended. Charging times for all PEVs vary widely depending on the size of the onboard energy storage system and the driving habits of the operator. Level 1 charging is most effective when the vehicle can be recharged in less than 8 to 10 hours (about 30-40 miles of electric driving). For example, using Level 1 to fully recharge a Chevrolet Volt will take about 8-10 hours while fully recharging a Nissan Leaf takes up to 20-24 hours. The Level 1 EVSE is typically provided with the new vehicle, so Level 1 charging has zero additional cost to the PEV owner as long as an outlet is available near the vehicle parking location.

Level 2 AC Charging

Level 2 charging can fully recharge a PEV in less than eight hours depending on the battery size and operator driving habits. Level 2 EVSEs require 208-240 volt single phase supply with 32-amp maximum continuous current and 40-amp branch circuit protection. Level 2 charging service also requires additional grounding, personal protection system features, a no-load make/break interlock connection, and a safety breakaway for the cable and connector.

Figure 3-1 compares maximum charge power for Level 1 (1.4kW) through the maximum allowed at Level 2 (19.2 kW) to average peak summer demand for households in five different U.S. cities with different climates. Likely implementations of residential Level 2 charging will likely range from a 15 amp circuit (12 amp continuous, 2.88 kW) to a 100 amp circuit (80 amp continuous, 19.2 kW). The higher capacity EVSE installations are more likely to impact the local distribution system.

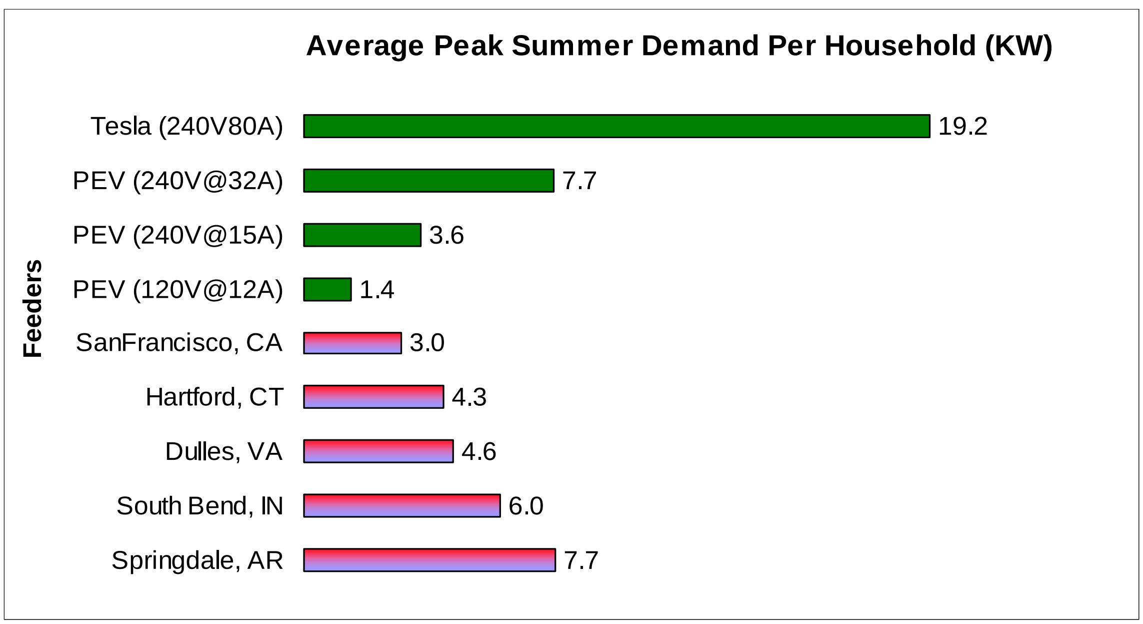

Figure 3-1
Relative comparison of charge power for AC Level 1 and 2 charging and average peak summer household demand.

DC Fast Charging

Fast charging is used for rapid recharges of PEV batteries and will most likely be found in commercial stations and PEV corporate fleet depots. Many manufacturers will include a fast-charge connection in addition to Level 1 or Level 2 charging connections on most PEVs, giving owners the option of quickly recharging their vehicles.

Overview of Electric Vehicle Supply Equipment

The following discussion looks at the function, safety features and installation of alternating current (AC) electric vehicle supply equipment (EVSE) hardware for the United States. There are three primary documents related to EVSE that are detailed in this overview:

- Society of Automotive Engineers J1772[4]
- National Fire Protection Association, National Electric Code, NFPA-70[5]
- Underwriters Labs Outline Investigation UL 2594[6]

The National Electric Code (NEC) defines EVSE as:

"The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatus installed specifically for the purpose of delivering energy form the premises wiring to the electric vehicle"[7]

That is, the EVSE is everything from the wall socket or wiring connection to the vehicle skin as seen in Figure 3-2.

First and foremost, the function of EVSE is to safely provide AC charging energy to a plug-in electric vehicle (PEV). The EVSE must follow protocols that ensure that AC power is only delivered to the cable and plug when a PEV has been properly connected. In addition to these basic safety functions, the EVSE may also provide informational displays, fee collection capabilities, power metering circuitry and other features appropriate to specific applications.

One question that a consumer may ask is - "Why is special hardware needed to plug a vehicle in? Why can't we just plug it in like any other appliance?" There are several reasons that have driven the NEC to require special hardware:

- PEVs are likely to be plugged in under non-ideal conditions, such as in wet or outdoor locations
- Many of the typical outlets used for providing 208/240Vac power are not designed for frequent connect/disconnect cycles
- There is a need for the EVSE to "tell" the PEV how much power it can draw from an outlet, as the PEV may be capable of charging at a higher power level than a charge port can provide

For wet and/or outdoor locations, the current NEC requires the use of ground fault current interruption (GFCI) devices. The GFCI is a device that detects when current is diverted from its normal flow path through an appliance so that it can disable the electrical circuit to prevent accidental electrocution. The NEC requires GFCI outlets to be installed near sinks, in garages and in outdoor locations. Since there is no way to ensure that a PEV will be plugged into a GFCI protected outlet, the NEC requires that the vehicle charge cord carry an integral ground fault protection device. To distinguish these devices from typical GFCIs, they are referred to as Charge Current Interruption Devices (CCID).

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[4] Society of Automotive Engineers, Recommended Practice J1772, available at www.sae.org

[5] National Fire Protection Association, National Electric Code, NEC-70, available at www.nfpa.org

[6] Underwriters Labs, Outline of Investigation 2594, available at www.ul.com

[7] NEC-70, Article 625.2

Figure 3-2
EVSE is all the hardware from the electricity source to the vehicle skin.

Connection at the Plug-In Vehicle

The Society of Automotive Engineers (SAE) has defined a common standard for the charging receptacle of a PEV in SAE Recommended Practice J1772. This receptacle is used for both Level 1 and Level 2 AC charging, which are defined and described in more detail in the following section. Figure 3-3 shows examples of the receptacle and plug.

Defining a standard interface ensures that both public and private charging infrastructure will work across PEV and EVSE brands.

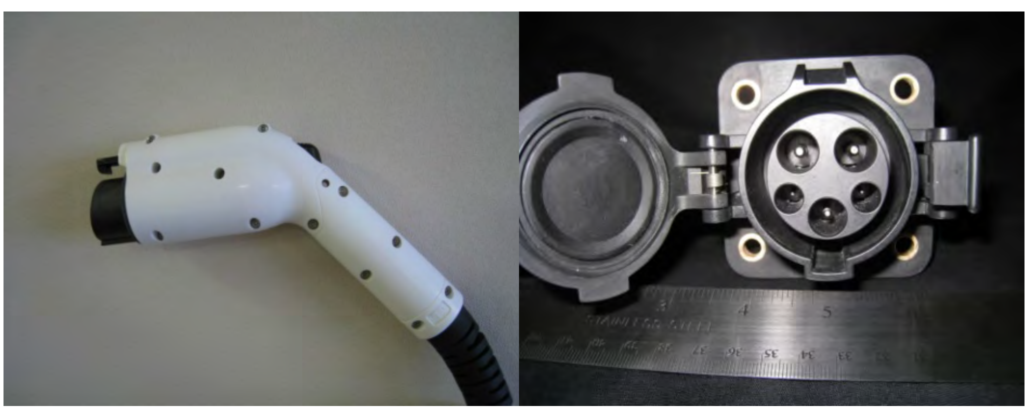

Figure 3-3
Example J1772 Plug (left) and PEV Receptacle (right)

Definition of Charging Levels

Plug-in electric vehicle AC charging levels are defined by the voltage level used. AC Level 1 chargers are designed to operate from 120Vac using a standard wall outlet. There are two types of standard 120Vac wall outlets as defined by the National Electrical Manufactures Association[8] (NEMA). A NEMA 15R receptacle is rated for 15 amps of current and the NEMA 20R receptacle is rated for 20 amps of current. Figure 3-4 shows a NEMA 15R outlet, which is most common outlet seen in residential settings and is the typical wall outlet that many consumer products are designed to operate from. A NEMA 15R receptacle can provide up to 1440W of charging power.

AC Level 2 chargers are designed to operate from 208VAC or 240VAC. 208VAC is typically found in commercial and industrial settings, while 240VAC is more commonly found in residential settings. Most high power appliances, such as, ovens, heating and ventilation equipment and water heaters operate from 208/240VAC. The higher voltage allows for higher power to be delivered at a given current level. Most 208VAC/240VAC appliances are hard wired, but some, such as clothes dryers, are cord and plug connected. Figure 3-5 shows one style of 240VAC plug often referred to as a "dryer plug" due to their common usage in powering clothes dryers. This type of plug is not well suited for frequent handling (note large exposed copper pins) and is not designed for large numbers of insertion/removal cycles.

EVSE Hardware

There are many manufactures of EVSE hardware. While the various brands of EVSE may look different, each provides a common set of basic safety features and the SAE J1772 plug interface. Level 1 EVSEs are designed for portable operation and often resemble contractor style extension cords as seen in Figure 3-6. Most vehicle manufactures include a Level 1 cord set with the vehicle.

Level 2 EVSE hardware must address additional requirements imposed by the NEC for 208/240VAC charging. One of these requirements is that the there be a safety mechanism that removes power from the cable/plug combination prior to the cable rupturing should a vehicle drive or drift away from a charge station while on charge. This requirement requires that the Level 2 EVSE be rigidly affixed to a stationary surface or object. Figure 3-7 shows several examples of Level 2 EVSE hardware.

EVSE Product Safety, Function and Installation

For EVSE products in the US, there are three primary organizations that cover product function, installation and safety as shown in Figure 3-8. While there is overlap of product safety issues across these three bodies, SAE primarily defines the standards and recommended practices for product function; UL writes standards to which products can be tested for safety; and the NEC describes how the product must be installed. Development of EVSE product standards has required the crossing of some traditional boundaries amongst these standards bodies as SAE has previously only operated within the vehicle skin, while UL has not been involved in the vehicle product standards space.

[8] National Electrical Manufacturers Association, www.nema.org

Figure 3-4
A NEMA 15R 120VAC Receptacle Can Be Used for Level 1 Charging

Figure 3-5
A 30 Amp Rated, 240VAC "Dryer Plug"

Figure 3-6
Examples of Level 1 (120VAC) EVSE Hardware

Figure 3-7
Examples of Level 2 (208/240VAC) EVSE Hardware. Note that all units are wall or pedestal mounted

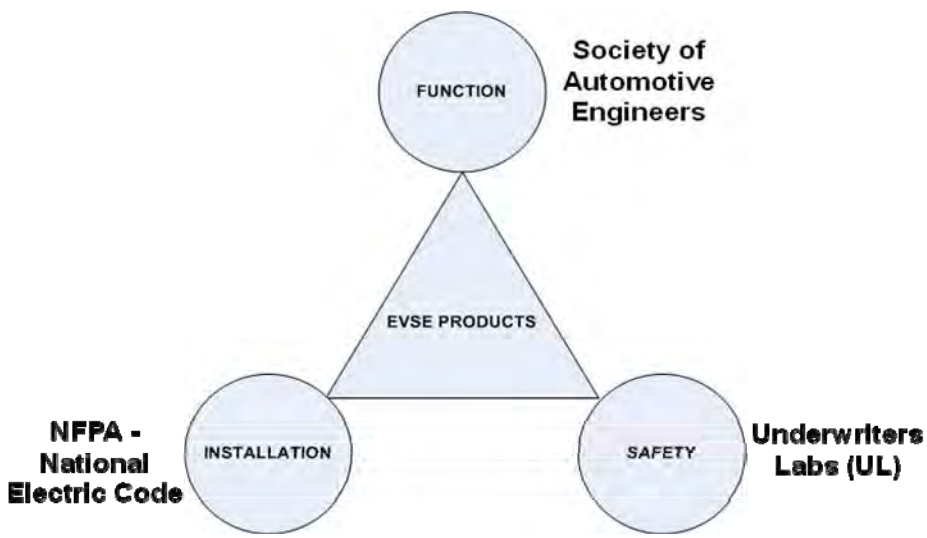

Figure 3-8
The EVSE Product Function and Safety Space

Basic EVSE Features as Required by the NEC

While the NEC primarily addresses EVSE in article 625 of the code, unless article 625 explicitly states that it supersedes other code requirements, all other aspects of NEC must be understood and observed to cover in relation to safe installation of EVSE.

Article 625 is designed to capture the specific and unique requirements for safe application of EVSE and covers a number of features that EVSE must. Which features are required is determined by the charging voltage level, with Level 1, cord-set type EVSE being exempt from some safety features that are required for Level 2 EVSE. The primary safety requirements include:

- The EVSE must monitor the integrity of the service ground connection and the ground connection at the output of the EVSE (applicable to both Level 1 and Level 2 EVSE)

- The EVSE must de-energize the cable/plug combination when not connected to a vehicle (Level 1 EVSE are exempt from this requirement, but implementation of J1772 makes this a mandatory feature for all EVSE)
- The EVSE must de-energize the cable/plug combination prior to a cable or connector failure due to strain induced by a vehicle moving away from the EVSE while on charge (Level 1 EVSE are exempt from this requirement)
- The EVSE must provide Charge Current Interruption Device functionality (applicable to both Level 1 and Level 2 EVSE)

Outlines of Key Standards

SAE J1772

The Society of Automotive Engineers Recommended Practice J1772 covers most of the functional aspects and plug/receptacle electrical and physical aspects.

- Scope
- References
- Definitions
- General Conductive Charging System Description
- Control and Data
- General EV/PHEV Requirements
- General EVSE Requirements
- Coupler Requirements
- Charge Status Indicator
- Connector/Vehicle Inlet Optional Marking
- Notes

UL 2594

Underwriters Labs Outline Investigation UL 2594 covers a broad range of product safety functions and implementation.

- General
- Frame and Enclosure
- Protection of Users -
- Protection Against Electric Shock
- Corrosion Protection Against Electric Shock
- Mechanical Assembly
- Supply Connections
- Output Connections and Wiring
- Equipment Grounding
- Bonding
- EV Bonding
- Internal Wiring
- Flammability
- Current Carrying Parts
- Electrical Connections
- Gaskets
- Spacings
- Alternate Spacings –
- Separation of Circuits
- Control Circuits
- Switches and controls
- Capacitors and Resistors
- Fuses and Other Circuit Protective Devices
- Transformers
- Printed Wiring Boards
- Insulating Materials
- Protection of Service Personnel
- Electronic Protection Circuits
- Cord Reels

NFPA-70, National Electric Code, Article 625

The National Electric Code covers the full range of installation requirements for EVSE. Note that in the outline below, the numbers following the content descriptions are the NEC paragraph numbers.

- General
- Scope, definitions, other articles, voltages, listed or labeled (625.1, 625.2, 625.3, 625.4, 625.5)
- Wiring Methods
- Electric vehicle coupler (625.9)
- Equipment Construction

- EVSE defined, rating, marking, means of coupling, cable, interlock, automatic de-energization of cable (625.13, 625.14, 625.15, 625.17, 625.18, 625.19)
- Control and Protection
- Overcurrent Protection, personnel protection system, disconnecting means, loss of primary source, interactive systems (625.21, 625.22, 625.23, 625.25, 625.26)
- Electric Vehicle Supply Equipment Locations
- Hazardous (classified) locations, indoor sites, outdoor specs (625.28, 625.29, 625.30)

Product Certification

Most consumer products sold in the US are agency listed and/or labeled for their intended use. The process of product listing involves testing and validating that the product meets minimum standards for safe operation in its intended use. Labs that perform such testing must be certified by the Occupation Safety and Health Administration (OSHA) as Nationally Recognized Testing Labs (NRTLs). A listing of the labs currently certified as NRTLs is given in Table 3-2[9]. Note that these labs perform many types of product safety testing and may or may not perform specific types of electrical product testing. NRTLs perform product testing against accepted product standards, listing the product as meeting that particular standard.

Underwriter Laboratories (UL) is the primary developer of product safety standards in the US. For EVSE products, UL has developed Outline Investigation 2594 [footnote] (often referred to as UL 2594). This UL standard defines both functional requirements and safety features that must be provided by EVSE. In addition, it defines a comprehensive set of tests designed to validate that an EVSE product will operate safely for typical usage patterns and in the typical environments where they will be found. To date, EPRI is aware of EVSE manufacturers having used CSA, UL, Intertek (ETL) and TUV-SUD for product listing.

Installations of electrical equipment must be reviewed and approved by an Authority Having Jurisdiction (AHJ). For most installations this is a governmental Electrical Inspector. Commercial facilities often have an in-house AHJ that is responsible for plant safety. One of the primary functions of product listing is that it gives confidence to Electrical Inspectors and AHJs that the product is suitable for its application and is safe for use. Note that listing does not ensure that a product is properly installed and/or is being used for its intended purpose.

Figure 3-9 shows some typical product markings that indicate the product has been listed.

Finding out if a product has been listed by an NRTL can be difficult. Some of the NRTLs maintain readily accessible on-line databases[10] of listed products while others do not. All listed products should have a mark or sticker indicating listing with the symbol or logo of the listing agency displayed. NRTLs generally have file or listing numbers that they require the listed product to display. These can be used to contact the listing NRTL to verify the legitimacy of the listing.

In the late 1990's a small number of companies were involved in making equipment to support PEV charging. The significant number of PEV announcements made by automotive manufacturers has attracted many companies into the EVSE manufacturing arena. A web survey conducted in late 2010 found 27 EVSE vendors, but at that time only a small handful had listed products. A repeat survey in early 2011 found 37 vendors with 11 vendors having some listed products. It is expected that most of these companies will have some listed products by the end of 2011.

[9] The OHSA list of NRTLs can be found at: http://www.osha.gov/dts/otpca/nrtl/

[10] Some examples: UL - http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.html;

CSA - http://directories.csa-international.org/; Intertek - http://etlwhidirectory.etlsemko.com/WebClients/ITS/DLP/products.nsf/$$Search

Table 3-2
List of OSHA Nationally Recognized Testing Laboratories

Canadian Standards Association (CSA) (also known as CSA International)
Communication Certification Laboratory, Inc. (CCL)
Curtis-Straus, LLC (CSL)
FM Approvals LLC (FM) (formerly Factory Mutual Research Corportaion)
Intertek Testing Services NA, Inc. (ITSNA) (formely ETL)
MET Laboratories, Inc (MET)
NSF International (NSF)
National Technical Systems, Inc. (NTS)
SGS U.S. Testing Company, Inc. (SGSUS) (formerly UST-CA)
Southwest Research Institute (SwRI)
TUV SUD, America, Inc. (TUVAM)
TUV SUD Product Services GmbH (TUVPSG)
TUV Rheinland of North America, Inc. (TUV)
Underwriters Laboratories, Inc. (UL)
Wyle Laboratories, Inc. (WL)

Figure 3-9
Examples of EVSE Product Listing Labels

An Overview of Charging Plug-In Electric Vehicles with Direct Current

While standards and practices for charging of PEVs with AC current has been established over the last year, there is still no standard for direct current (DC) charging of PEVs in the US. The primary lead in establishing these standards for the US is the Society of Automotive Engineers. SAE currently has four documents that relate to DC charging of PEVs:

- SAE J2836/2 - Use Cases for Communication between Plug-in Vehicles and Off-Board DC Charger
- SAE J2847/2 - Communication between Plug-in Vehicles and off-board DC Chargers
- SAE J2931 – Power Line Carrier Communications for Plug-in Electric Vehicles
- SAE J1772 – SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

Of these documents, the J2836/2 and J2847/2 documents are the most mature. The first versions of these are expected to be balloted by the middle of 2011.

The J2931 document is not as well developed with some major decisions related to the communications technology and medium yet to be made. SAE is reviewing three possible communications technologies, all based on transfer of data over existing wires in the charge cable, that is, without special wires dedicated to the communications function. This technology is referred to as Power Line Carrier (PLC) and has been widely used in other applications for many years.

The J1772 committee is currently focusing on the physical layout of the DC connector. This effort will be discussed in detail in a later section.

As has been done with AC charging, the SAE has defined charging levels for DC. For DC charging, the voltage at which charging occurs is dependent on the vehicle battery and that battery's control system. As such, the charge levels are not defined on voltage level (as was done with AC), but by the power level of charging delivered:

- **DC Level 1** – 200-450V
  - Rated Current <=80A
  - Rated Power <= 19.2kW
  - DC transfer using the existing J1772 AC connector
- **DC Level 2** – 200-450V
  - Rated Current <=200A
  - Rated Power <= 90kW
  - DC transfer using the combo connector (see discussion following on the combo
- **DC Level 3** – 200-600V
  - Rated Current <=400A
  - Rated Power <= 240kW
  - Proposed connector is TBD

The SAE J1772 DC Connector Effort

The SAE J1772 committee has been working to define the DC charging connector for DC Level 2 charging in the US. What has been proposed by SAE is referred to as the combo connector as it combines the existing AC connector footprint with added high current DC charge pins. A mockup of the proposed combo connector is shown in Figure 3-10.

Testing is underway to validate the combo connector concept. The concept has also been adopted within the International Electrotechnical Committee (IEC) as part of the proposed standards at the world level.

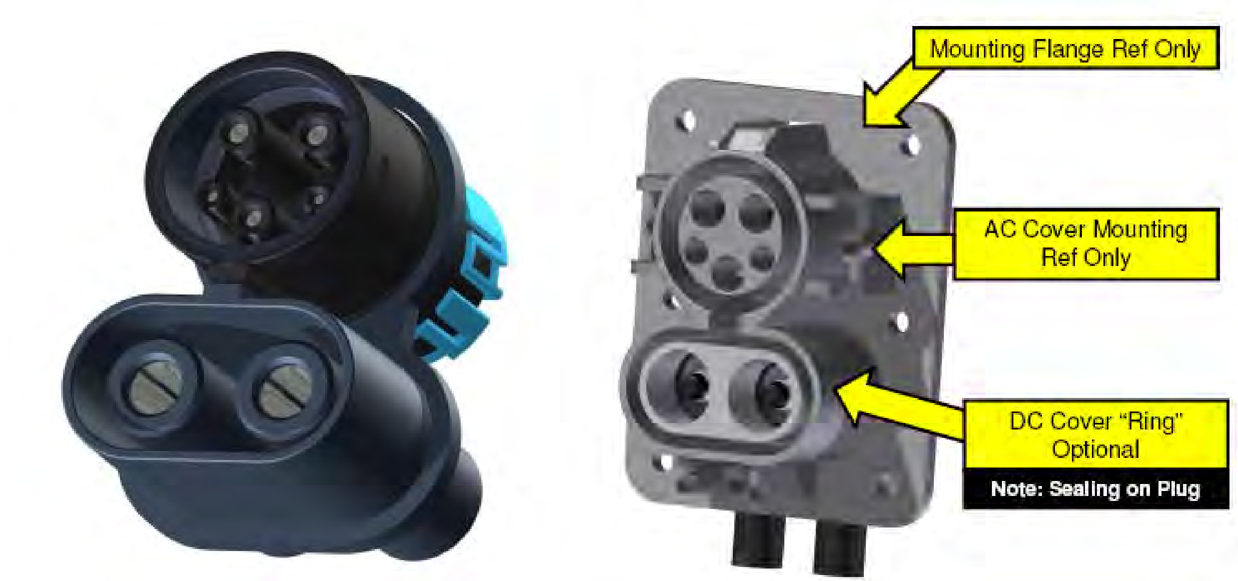

Figure 3-10
Proposed SAE Combo Connector schematic with plug (left) and receptacle (right). Images courtesy of General Motors and REMA.

Near Term Deployment of DC Chargers

There are a number of demonstration programs under way in the US that will deploy the Japanese DC fast charging standard. Referred to as CHAdeMO, this standard was developed in Japan by the Tokyo Electric Power Company and the Japan Automotive Research Institute. The CHAdeMO charger is classified as a DC Level 2 charger by SAE. A number of companies have licensed the technology and are producing or planning to produce the chargers in the US. There are currently only two of the CHAdeMO chargers deployed in the US, one in Portland, Oregon and one in Vacaville, CA, but it is expected that nearly 100 of the CHAdeMO chargers will be deployed by the end of 2011 in the US. Figure 3-11 shows a photo of the CHAdeMO unit installed in Vacaville and a unit on display at a trade show. The CHAdeMO plug is shown in Figure 3-12 and the receptacle in Figure 3-13.

Figure 3-11
A CHAdeMO DC Fast Charger installed in Vacaville, CA (left); an Eaton DC Fast Charger on display at the Plug-In 2010 Conference.

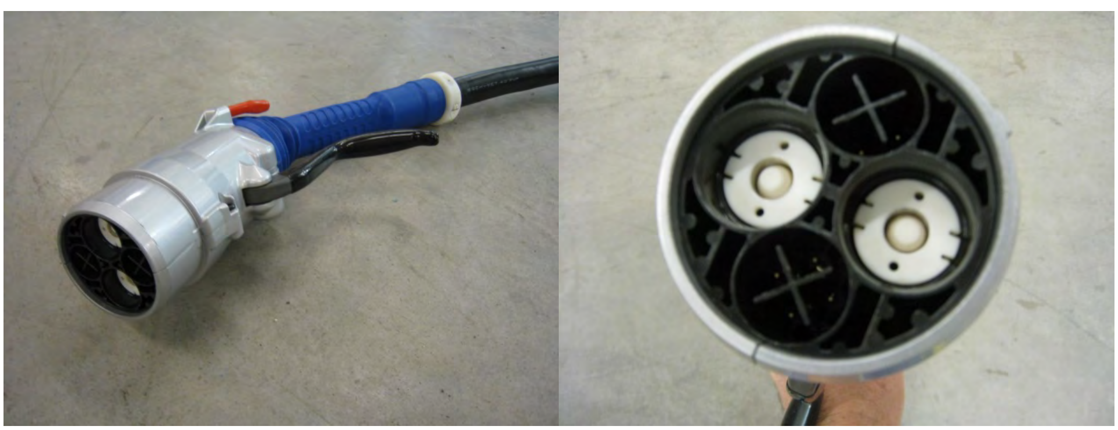

Figure 3-12
The CHAdeMO Plug

Figure 3-13
The CHAdeMO Receptacle

Infrastructure Cost Estimates

Due to the very specific nature of analyzing infrastructure costs in a single utility service territory, there is naturally not a lot of relevant and publicly available information. A review of available literature found one relevant report, by the U.S. Department of Energy. Inquiries among electric utilities found five utilities that had engaged in significant analyses of either existing charging infrastructure installation cost data or had performed other work to estimate costs in their service territory. These five utilities are:

- Southern California Edison
- Detroit Edison
- Progress Energy
- Georgia Power
- Sacramento Municipal Utilities District

Review of Installation Cost Estimates

In November, 2008, Idaho National Laboratory published the report, "Plug-In Hybrid Electric Vehicle Charging Infrastructure Review[11]" containing a brief section on cost analysis of infrastructure scenarios for residential, apartment, and commercial installations. The report was co-authored by Electric Transportation Engineering Corporation (ETEC), a firm with significant experience at installing electric vehicle infrastructure. The report stated the following residential infrastructure costs:

[11] Idaho National Laboratory, *Plug-In Hybrid Electric Vehicle Charging Infrastructure Review,* INL/EXT-08-15058. Nov. 2008

Table 3-3
Idaho National Lab Scenario Estimates for Charge Infrastructure Installation.

Installation Scenario	Per Charge Port Installation Cost	
	Level 1 – 120 VAC	Level 2 – 240 VAC
Residential (single charge station)	$ 878	$ 2,146
Apartment (five charge stations)	$ 833	$ 1,520
Commercial (ten charge stations)	N/A	$ 1,852

Costs include EVSEs ($250 for Level 1 cordset, $650 for Level 2 EVSE), labor, material, permitting, and administrative costs. It is important to note that while these assumptions may be derived from ETEC's prior experience at installing infrastructure, predominantly in the Phoenix metropolitan area, the report does not explicitly state this. Panel upgrades, concrete or asphalt cutting, and trenching were not assumed to be necessary for any of the installation scenarios.

Utility Survey

Five of the utilities surveyed by EPRI were either conducting relevant analyses or possessed data regarding charging infrastructure costs. Of the five, Detroit Edison and Southern California Edison (SCE) both worked with a dataset from Clean Fuel Connection, a company responsible for a large fraction of historical and recent EVSE installations.

Clean Fuel Connection and EPRI conducted a detailed analysis of EVSE installation costs relative to housing stock in the SCE service territory. The study identified several parameters as important drivers of EVSE installation cost—available electrical panel capacity, age and size of home, and location of parking relative to the electrical panel.

Table 3-4
Level 2 EVSE Installation Costs

Type of Installation	Average Installation Cost
Residential, per unit	$ 1,501
Commercial, per unit	$ 2,498

Sacramento Municipal Utilities District (SMUD) installed approximately 1,900 EVSEs from 1991 to present. These consisted of both inductive and conductive EVSE. A portion of SMUD's data comes from installations done by CFCI as a subcontractor to SMUD in the 1990s.

SMUD encountered approximately 13% of residential installations requiring a panel upgrade. The average reported cost of the panel upgrades was $1,305. SMUD also reported that service calls were frequent and averaged about $255 per call. This cost is for labor only.

Georgia Power recorded actual installation costs (without equipment) for 88 residential charging installations in the Atlanta area in 1999. These Level 2 installations were primarily to serve battery electric vehicles, either the General Motors EV1 or the Ford Ranger EV. Georgia Power reported an average installation cost was $336.18. This low cost is probably a result of the result of regional differences in labor costs as well Georgia Power's efforts to streamline and simplify the installation process. This likely also reflects labor savings realized through a combination of directly employing the electricians performing the work and eliminating time spent bidding and permitting each installation[12].

[12] Georgia Power worked with local jurisdictions to explain the charge port installation process and became effectively self-permitting as a result of this effort.

Table 3-5
Installation Cost Estimates for SMUD

Installation Type	Labor	Permits	Materials	Tax	Total
Residential	$ 1,177	$ 150	$ 572	$ 193	$ 2,092
Commercial	$ 2,287	$ 77	$ 1,497	N/A	$ 3,861

Georgia Power also reported data on six retail shopping mall installations in the same area. Each installation consisted of 5-6 Level 2 EVSE, supported by a pad-mounted 75 kVA power supply capable of supporting up to 11 EVSE at each location. A total of 31 charge ports were installed in six separate locations. The average cost of each location was $23,666 with a per EVSE cost of $4,581.

One limitation to existing EVSE installation data is that it is generated by the residences of the current set of electric vehicle adopters. Any differences between this group and later market adopters will be reflected in this data. Progress Energy, with support from EPRI, approached this issue in a different way, by conducting opportunity audits of their residents and estimating 120V and 240V installation costs throughout their service territory. These estimates were conducted by professional electricians who were paid approximately $5 per residence to fill out a simple questionnaire. The data was collected during normal service calls by these electricians to homes with Progress Energy's service territories in North/South Carolina and Florida.

Table 3-6
Progress Energy Installation Costs Estimates

Cost to Install 240V Dedicated Circuit (30 amp)	Location	
	Carolinas	Florida
$100 - $250	10%	35%
$250 - $500	60%	52%
$500 - $750	19%	8%
$750+	12%	6%

While this data, in its current form, is not directly applicable to this analysis, Progress Energy was able to show that low-cost, professional estimates of over 2,500 residences in its service territory could be obtained in this manner.

The evaluation of the existing information indicates that generalizations about cost are difficult to make given the variety of ways in which data were collected. There are also potential regional differences in cost. No source of comparable data exists against which to compare the results of this study.

Equipment Costs

Equipment costs are a significant portion of the total cost of installing residential, workplace, or public charging infrastructure. Equipment refers to the EVSE (Level 1 or Level 2) for AC charging and the off-board charge station for DC charging.

The electric vehicle charging equipment industry is experiencing rapid evolution. There are numerous companies currently developing products, testing and certification times are long, and there is a significant amount of federal and state funding for infrastructure deployment and demonstration. As a result, equipment costs, while definitely decreasing, are still somewhat uncertain.

Existing manufacturers are also transitioning to a new generation of devices intended to meet stricter cost targets and lower retail prices. Today's costs are relatively high, ranging from $490 for a Level 2, 20-amp EVSE to several thousand dollars for dedicated public EVSEs with sophisticated communication and billing capabilities.

The EVSE market is highly competitive and suppliers are reluctant to provide cost information on their units. EPRI extensively surveyed EVSE suppliers (both existing and future) and representatives from the automotive industry to attempt to frame the near-term EVSE cost issues. From this survey, EPRI drew the following estimates and conclusions regarding the EVSE market:

- Next-generation EVSE units are targeting a wholesale price at or below $1,000 for exterior commercial grade units. This may or may not include communications capabilities, however the added cost of this feature is nontrivial.
- Automotive OEMs are either developing their own EVSE for near-term sales or have approached suppliers to build a unit to their specifications. These EVSEs typically do not have communications capability. Cost targets for these units range from a few hundred dollars up to $800.
- The cost of the SAE J1772 connector is uncertain, but estimated cord and connector costs are roughly $100 – $200.
- Higher volume production and competition will drive the EVSE manufacturers to a long-term cost target of approximately $500, though many admit this will be difficult to achieve.
- Pedestal and other mounting equipment (dual mount adapters, cordset retention, etc) can add several hundred dollars in cost to each unit.
- Estimates of the cost of adding communication capability vary widely from as little as $100 to half the cost of the EVSE ($500 – $1000).

EVSE costs should be monitored on a regular basis by working with the suppliers on volume quotes (minimum 500 units).

Equipment Maintenance

Maintaining the operability of a regional EVSE network is a significant challenge. Equipment installed in an outdoor, public, or other multi-user environment will experience degradation, damage, or other events that may affect availability at a significant frequency. This can include connector and cordset wear-and-tear, physical damage to the unit due to contact from vehicles or intentional vandalism, breaker trips, or failure of the internal electrical or electronic components. In addition, EVSE with network capabilities also require additional IT components and a back-end server system that must be maintained. As mentioned above, SMUD experienced frequent, costly service calls on their local EVSE infrastructure—typically conductive or inductive Level 2 units (without any communication or network capability).

Maintaining network operability is compounded by the complexity of EVSE ownership for many public charging installations. In a single family residential setting, a single PEV operator is likely using a single EVSE. If there is a problem with the EVSE, the individual is highly motivated to correct that problem. For public infrastructure, the EVSE may be installed and operated by one entity, could be located on either public or private property, possibly with a mix of public and private funding, etc. It may not be clear who is responsible for the equipment and the impact of the equipment downtime may not be obvious to the responsible party.

EVSE Infrastructure Ownership Models

Outside personally owned residential charging infrastructure (a home EVSE) there are roughly five models of ownership for charging infrastructure:

1. Municipally owned and operated for public benefit, similar to traffic signals, street lights, etc. Supported through municipal budgets.
2. Utility owned and operated for public benefit. Supported in the utility rate base.
3. Employer owned and operated as an employee benefit
4. Privately owned primarily to enhance an unrelated business—retail shopping, hotels, restaurants, private parking facilities, etc.
5. Privately owned and operated for the sole purpose of providing charging services to PEV owners.

Outside of residential charging installations, which are used for several hours per day, the cost of an EVSE installation is typically high relative to the total value of electricity it delivers. For ownership models where station revenue must generate a positive return on the capital invested in the installation, this will have the effect of increasing the cost to the user over and above what they would pay at their home charging location. If this cost is too high, the user is less likely to use the service, resulting in either limitations on BEV operation or increased gasoline consumption from PHEV operation.

It is already clear that there are a number of potential scenarios for the installation and ownership of charging infrastructure that are not strictly based on the revenue derived from charging electric vehicles. Examples can include:

- Businesses (restaurants, hotels, retail stores, etc) that will feature charging infrastructure to attract customers
- Parking lot or garage operators that may integrate charging into their existing billing system
- Automotive companies that sell PEVs and offer charging to their customers at dealerships or other locations to help create an early network of charging locations[13]
- Charging networks that operate on a membership basis—rather than a pay-per-use basis

[13] Nissan is already offering this in their early launch market dealerships.

Section 4: Plug-In Electric Vehicle Adoption Forecasting – Energy and Climate Impacts

This section presents preliminary PEV market forecasts. Understanding potential PEV adoption scenarios over a significant length of time is important to projecting energy and climate impacts. It is also a necessary input in grid impacts analyses, discussed in Chapter 5. Evaluating these impacts requires understanding the number of vehicles likely to be introduced and the charging patterns for those vehicles.

Market Projection Analysis

There is a high degree of uncertainty concerning how quickly PEVs can enter the market and grow in volume. Compared to other advanced vehicles like HEVs, PEVs are generally more expensive and more technologically risky for vehicle manufacturers, which reduce the likely rate of introduction. However, more manufacturers are introducing vehicles at the same time, in more vehicle classes, and with a much higher level of government and consumer support. This study considers three PEV adoption scenarios to quantify the effects of PEVs.

Scenario construction

PEV adoption scenarios were created for each state (and Washington DC) within the EV Project, the EV Project area as a whole, and the United States as a whole. Three scenarios for each region were derived as follows:

Low Scenario

- The PEV market share in 2010-2018 is based on the HEV sales performance in the overall passenger vehicle market in the U.S. from 2000-2008.
- From 2019 onward the PEV share is based on an extrapolation of HEV sales performance 10 years earlier.
- The PEV share in a particular region is biased up or down depending on the 2008 market share of HEVs in the region compared to the U.S. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

Medium Scenario

- From 2010-2015, the estimate of the PEV share of new vehicle sales is based on “ground-up” sales estimates, which in turn are derived from PEV launch announcements and (where available) production estimates.
  - In 2010-2011, the majority of PEV sales will occur in the launch markets announced by General Motors and Nissan for the Volt and Leaf, respectively. The rollout area extends beyond the EV Project area.
  - From 2012 through 2015, there is a decreasing residual effect where the launch markets have higher penetration than the U.S. average
  - The PEV share in a particular region is also biased up or down depending on the 2008 market share of HEVs in the region compared to the PEV launch markets
- After 2015, the PEV market share is based partially on an extrapolation of the “ground-up” estimates and partially on the past sales performance of HEVs.
  - The weighting of the “ground-up” extrapolation decreases in later years
  - The weighting applied to past HEV sales performance increases in later years. The effect of past HEV sales, *before weighting*, is calculated as follows:

- The PEV market share in 2016-2018 is based on the HEV sales performance in the region from 2006-2008, adjusted for the fact the HEVs were only available in a portion of the passenger vehicle market.
- From 2019 onward the PEV share is based on an extrapolation of HEV performance in the region 10 years earlier. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

High Scenario

1. The PEV market share is based on an average of publicly available forecasts. This scenario considers only the top third of the available studies.
2. The PEV share in a particular region is biased up or down depending on the 2008 market share of HEVs in the region compared to the U.S. However, based on an assumption that PEV technology becomes mainstream after 15-20 years, the regional bias is partially phased out in later years.

The split of PEVs into PHEVs and EVs is the same for all three scenarios. The mix begins with 50% PHEV40s and 50% EVs in 2010. PHEV10s are introduced in 2012 as 10% of the PEV market, ramping to 50% of PEVs by 2016. Over the period of 2012 to 2016, PHEV40s and EVs ramp down from 45% each to 25% each.

US-wide results summary[14]

The adoption scenarios were modeled using a market introduction analysis tool which utilizes annual mileage traveled statistics for the specific region being evaluated and expected vehicle energy consumption to calculate electricity consumption, gasoline savings, and CO_2 reduction. This section describes results for the United States as a whole.

Figure 4-1 shows the results for the number of PEVs in the United States for the analysis scenarios described above, over the period of 2010 to 2015. Under the medium scenario, there would be 1.2 million PEVs in 2015, while the results for the low and high scenarios in 2015 are about 0.6 and 2.4 million PEVs, respectively. The market adoption scenarios assume that PEVs continue to be sold in increasing numbers beyond 2015. Figure 4-2 illustrates the cumulative PEV fleet size through the year 2030. The fleet reaches approximately 5.8 million vehicles for the medium scenario in 2020, and due to the compounding effect of fleet growth, the number of PEVs grows fairly rapidly to just under 35 million by 2030. The total fleet under the low scenario is about 3.1 million in 2020 and just under 15 million by 2030. The high scenario projects a substantial number of PEVs on U.S. roads, reaching 12 million in 2020 and over 65 million vehicles by 2030.

Figure 4-3 shows the penetration of PEVs as a percentage of the total vehicle fleet (i.e., all vehicle ages) in the United States. The penetration under the low scenario is mild, passing through 0.2% in 2015, 1.0% in 2020, and reaching just 4.0% in 2030. The PEV penetration in the medium scenario is close to double that of the low: 0.4% of the vehicle fleet in 2015, 1.9% in 2020, and 9.4% in 2030. There is significant market penetration of PEVs into the vehicle fleet under the high scenario: 0.8% in 2015, 3.9% in 2020 and just under 17.7% in 2030.

[14] The VMT (vehicle miles traveled) forecast data used in this study was created by the Environmental Protection Agency in 2001, and thus does not include the effects of the 2008-2009 recession. This most likely means that the VMT is overestimated for the near-term (2010-2015).

The effects of overstated VMT on the results of this study would be as follows. The results for the medium scenario, which uses absolute numbers (rather than percentages) for the "ground-up" sales estimates, are accurate for the 2010-2015 period but are overstated in years after 2015. The medium scenario PEV new-vehicle market share percentages are understated for the 2010-2015 timeframe but accurate beyond 2015. The results for the low and high scenarios are overstated.

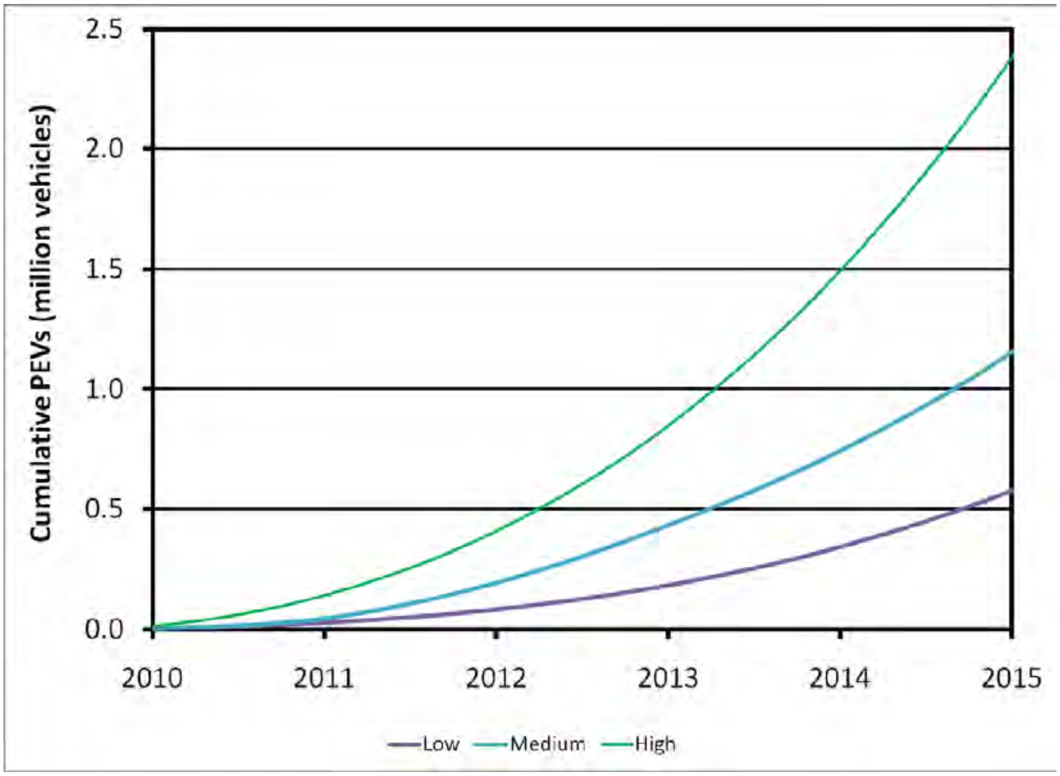

Figure 4-1
Cumulative PEV fleet to 2015 (U.S.)

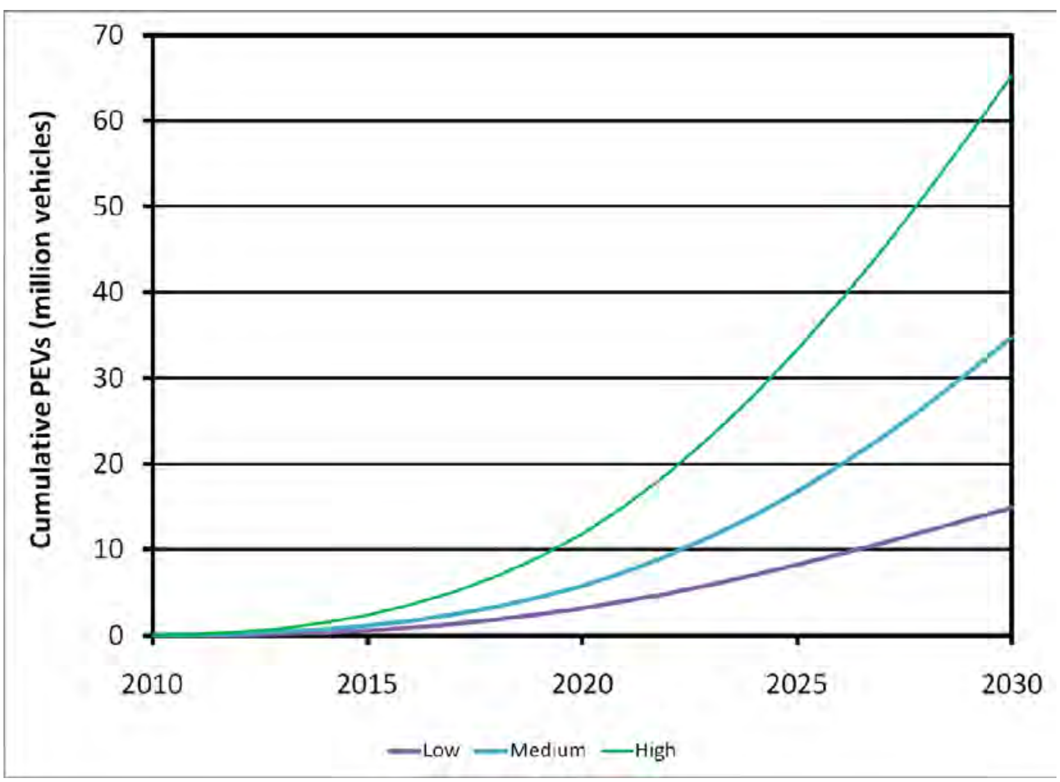

Figure 4-2
Cumulative PEV fleet (U.S.)

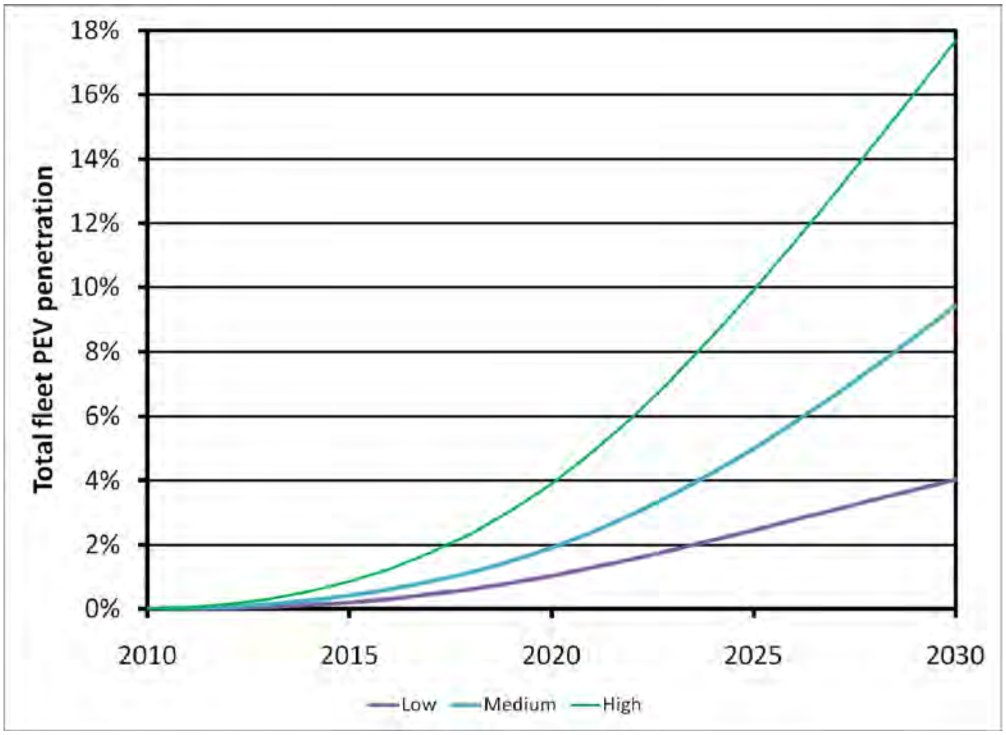

Figure 4-3
Penetration of PEVs in total vehicle fleet (U.S.)

Figure 4-4 shows the projected PEV electricity consumption, which under the medium scenario rises to about 4.4 TWh in 2015 and then 16 TWh in 2020. Due to continually increasing PEV sales over the 2020-2030 period, the electricity use due to PEVs climbs to just under 80 TWh in 2030. Since the split of PEV types is the same in all three scenarios (50% PHEV10, 25% PHEV40, and 25% EV after 2015), the average electricity consumption per PEV is nearly equal in the three scenarios. As a result, the electricity consumption results follow the same trend as the cumulative fleet results shown in Figure 4-2. In 2015, the PEV electricity use is about 2.2 TWh for the low scenario and just under 9.0 TWh for the high. By 2020 the consumption increases to 8.8 TWh and 33 TWh for the low and high scenarios, respectively.

Figure 4-5 shows the projected gasoline savings. The analysis compares the PEV adoption scenarios to a base case where HEVs are sold in place of the PEVs. Since the consumption of electricity by PEVs displaces a nearly proportional amount of gasoline, each projection of gasoline savings has the same shape as the corresponding electricity consumption (Figure 4-4), but with a magnitude expressed in billions of gallons of fuel per year. In the medium adoption scenario, the gasoline savings grow to about 380 million gallons in 2015, 1.4 billion gallons in 2020, and about 7.0 billion gallons per year in 2030. The low scenario gasoline savings are 190 million gallons in 2015 and 770 million gallons in 2020. The high scenario saves 790 million and 2.9 billion gallons in 2015 and 2020, respectively.

The PEV adoption tool estimates the amount of additional CO_2 emissions due to vehicle charging as well as the reduction in CO_2 caused by lower gasoline consumption. This analysis uses CO_2 emitted by national-average electricity production[15], the production of gasoline in California, and the consumption of gasoline by vehicles. Figure 4-6 illustrates the change in CO_2 emissions on an annual basis due to the introduction of PEVs in the U.S. overall. The chart shows that the net effect is a decline in CO_2 emissions in all years. The CO_2 reduction increases as a faster rate starting in 2025 because electricity's CO_2 emissions are expected to decline more rapidly beginning in that year. The emissions reduction in the medium scenario rises from roughly 2.1 to almost 48 million metric tons per year over the period from 2015 to 2030. Overall, the reduction is approximately 2 metric tons per PEV per year in the near term (2010-2015).

[15] The CO_2 reduction results for individual states are based on a specific CO_2 forecast for that area.

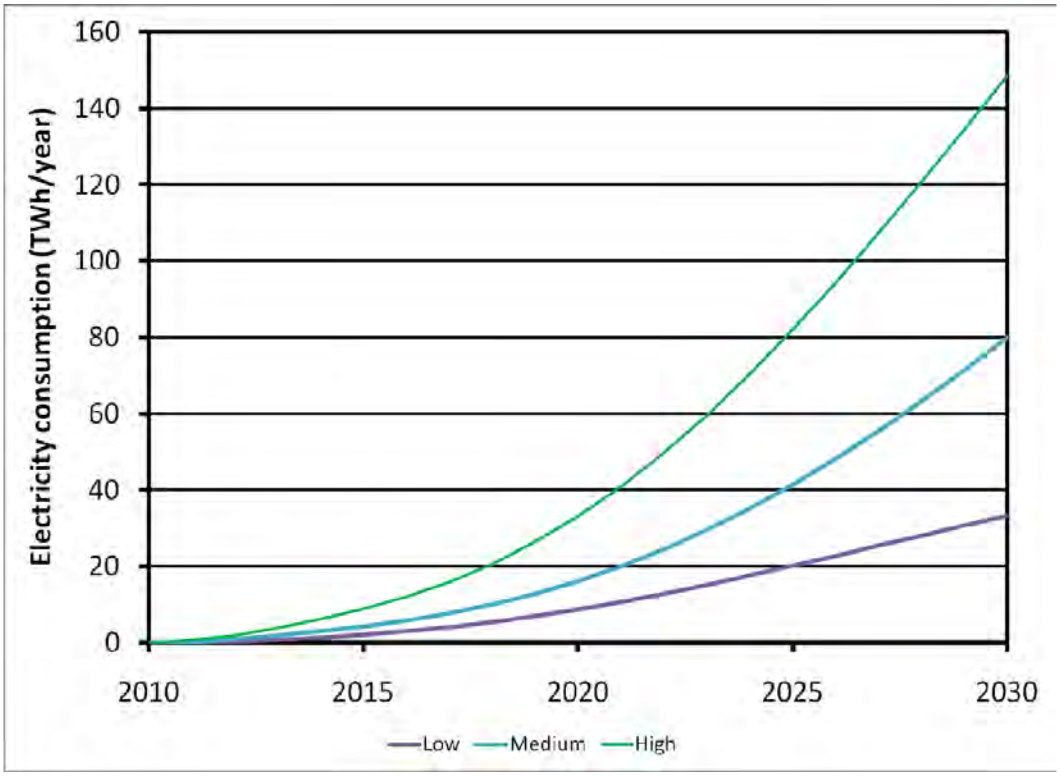

Figure 4-4
PEV electricity consumption (U.S.)

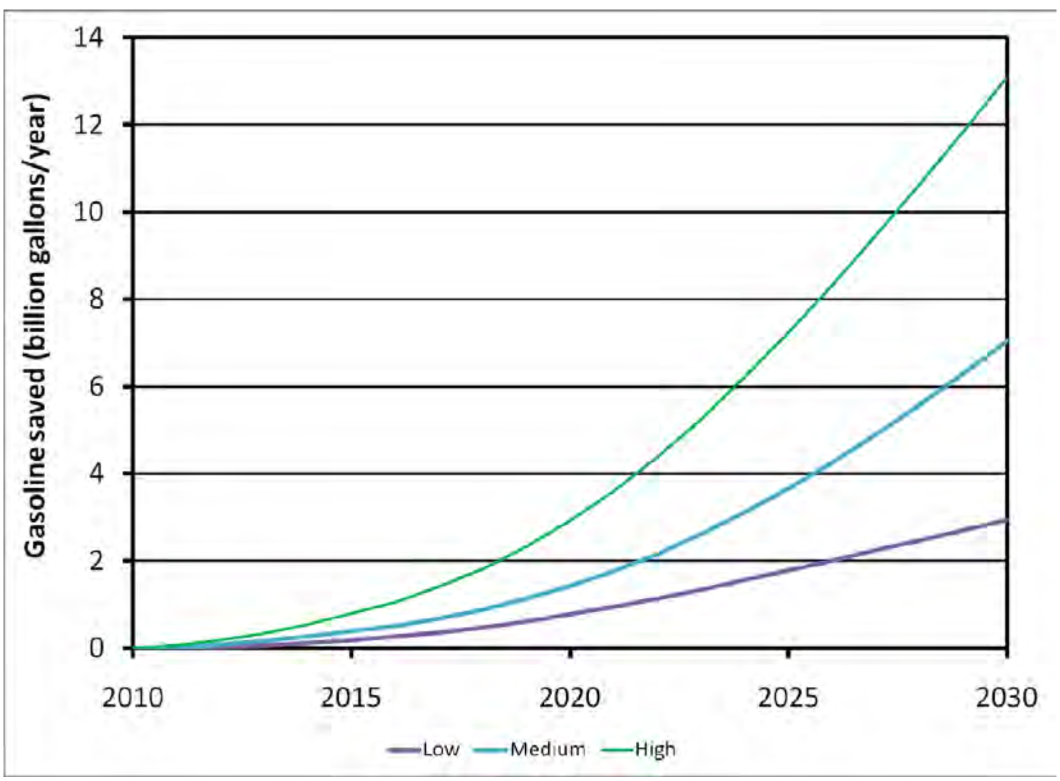

Figure 4-5
Gasoline savings for vehicle penetration scenarios (U.S.)

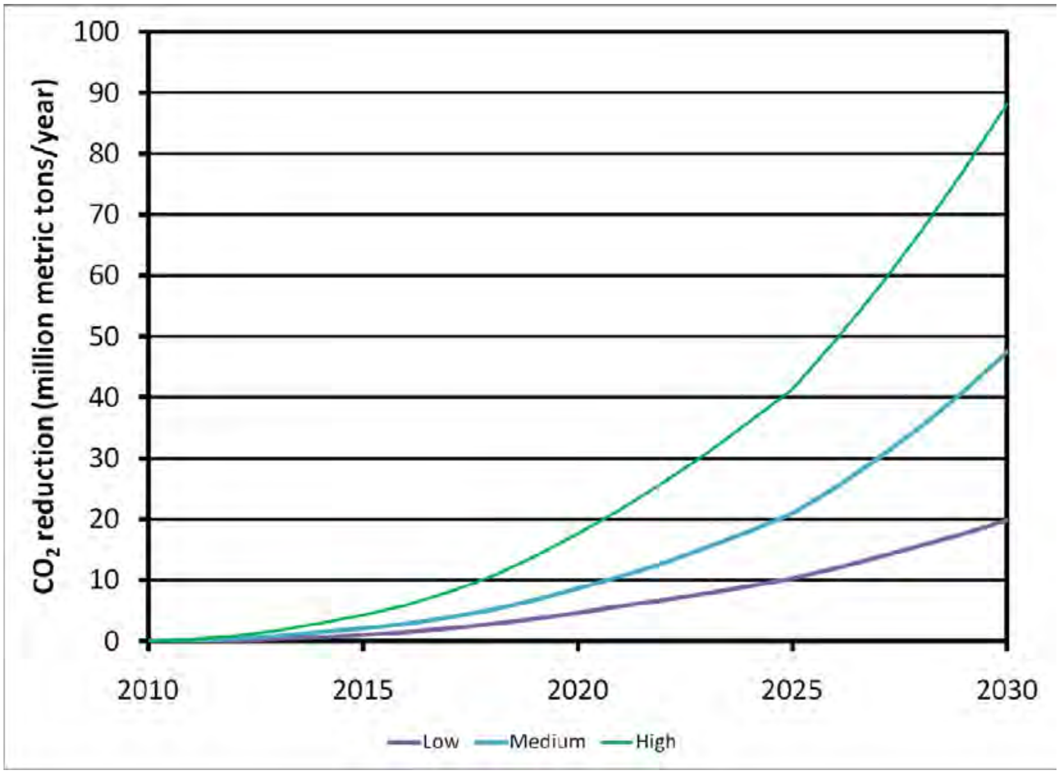

Figure 4-6
Estimated CO_2 reduction due to introduction of PEVs (U.S.)

EV Project area results summary

This section describes results for the EV Project deployment area, which currently includes six states (Oregon, Washington, California, Arizona, Tennessee and Texas) and the District of Columbia.

Figure 4-7 shows the results for the number of PEVs in the EV Project area for the three scenarios. In the medium scenario, there would be 0.5 million PEVs in 2015, about 2.3 million in 2020, and just under 12 million by 2030. The low and high scenarios in 2015 see about 240,000 and 1.0 million PEVs, respectively. In 2020 the total fleet is about 1.2 million PEVs in the low scenario and 4.5 million in the high scenario.

Figure 4-8 shows the PEV penetration in the overall vehicle fleet in the EV Project area. There are low levels of penetration in the low scenario: 0.3% in 2015, 1.4% in 2020, and growing to only 4.7% in 2030. The penetration of PEVs under the medium scenario is about twice that of the low scenario in the early years but grows more rapidly 10 to 20 years after the introduction of PEVs: 0.7% of the vehicle fleet in 2015, 2.6% in 2020, and 11% in 2030. The high scenario shows considerable market penetration: 1.3% in 2015, 5.2% in 2020 and just below 21% in 2030.

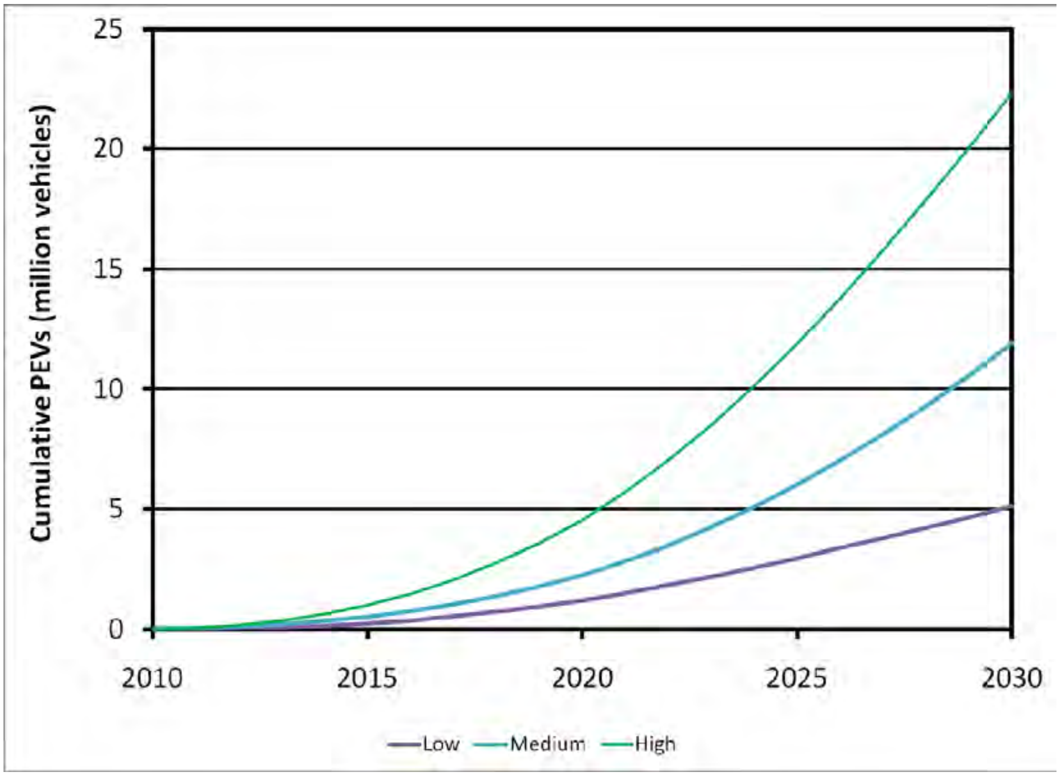

Figure 4-7
Cumulative PEV fleet

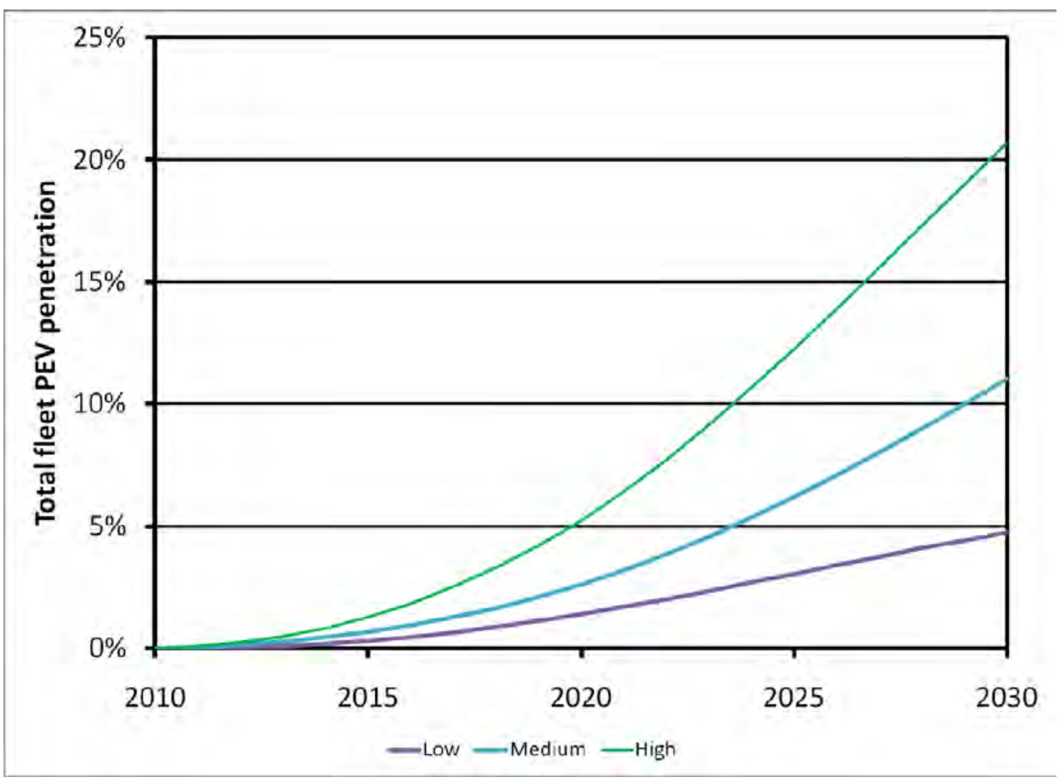

Figure 4-8
Penetration of PEVs in total vehicle fleet

Figure 4-9 shows the projected electricity usage of PEVs. In the medium scenario, consumption is just under 2.0 TWh in 2015, about 6.3 TWh in 2020, and rises to 27 TWh in 2030. In 2015, the PEV electricity use is 0.9 TWh for the low scenario and about 3.7 TWh for the high. By 2020, consumption is 3.3 TWh and 12.6 TWh for the low and high scenarios, respectively.

Figure 4-10 shows the decrease in gasoline consumption due to PEVs in the EV Project area. Under the medium scenario, the gasoline savings grow to about 170 million gallons in 2015, 550 million gallons in 2020, and about 2.4 billion gallons per year in 2030. The low scenario sees savings of 80 million gallons in 2015 and 290 million gallons in 2020, while the high scenario saves 330 million and 1.1 billion gallons in 2015 and 2020, respectively.

Figure 4-11 shows the CO_2 emissions reduction caused by PEVs in the EV Project area. In the medium scenario, roughly 0.9 million metric tons of CO_2 are avoided in 2015, rising to just over 16 million metric tons per year in 2030.

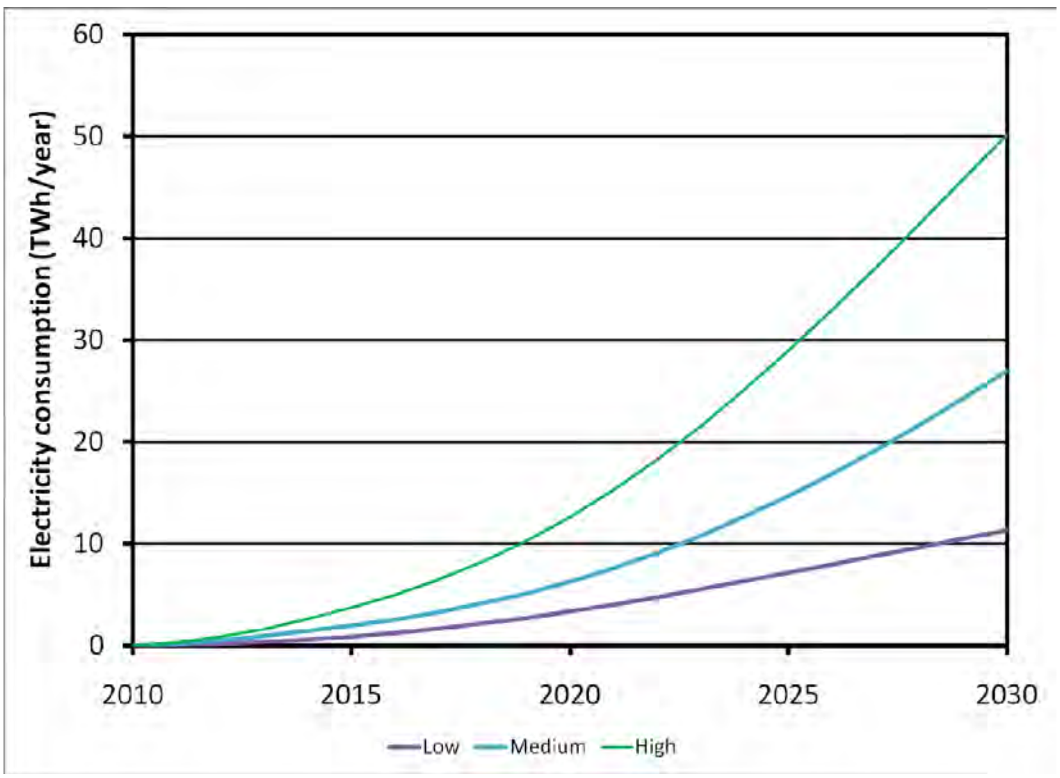

Figure 4-9
PEV electricity consumption

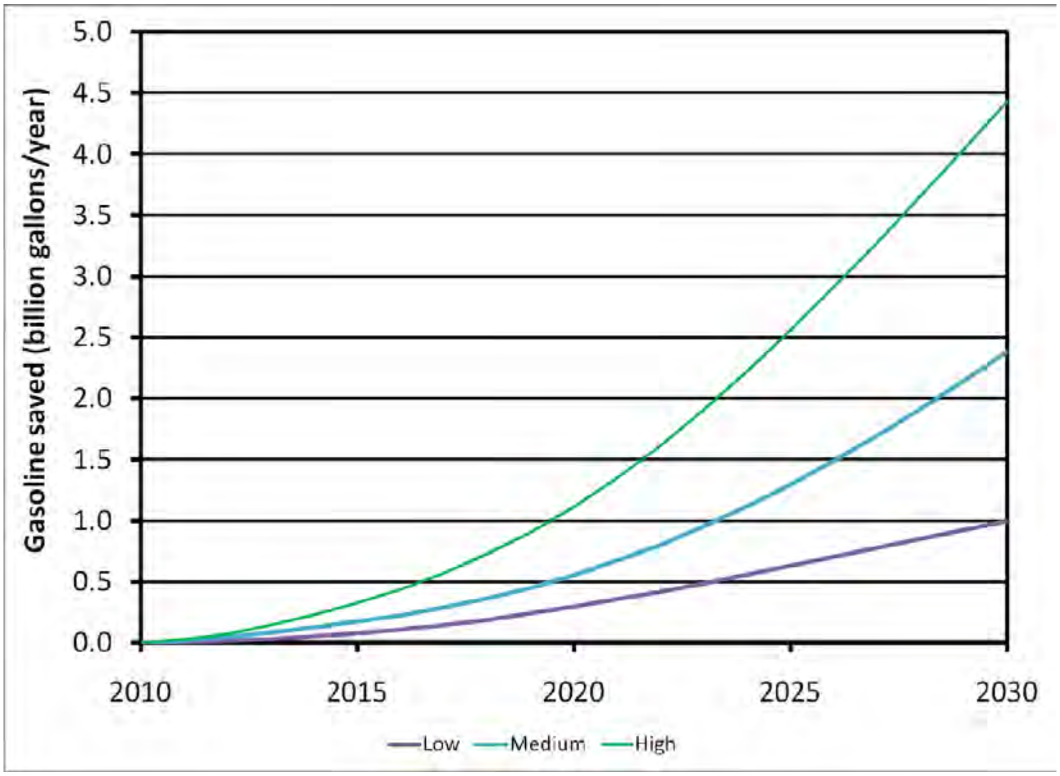

Figure 4-10
Gasoline savings for vehicle penetration scenarios

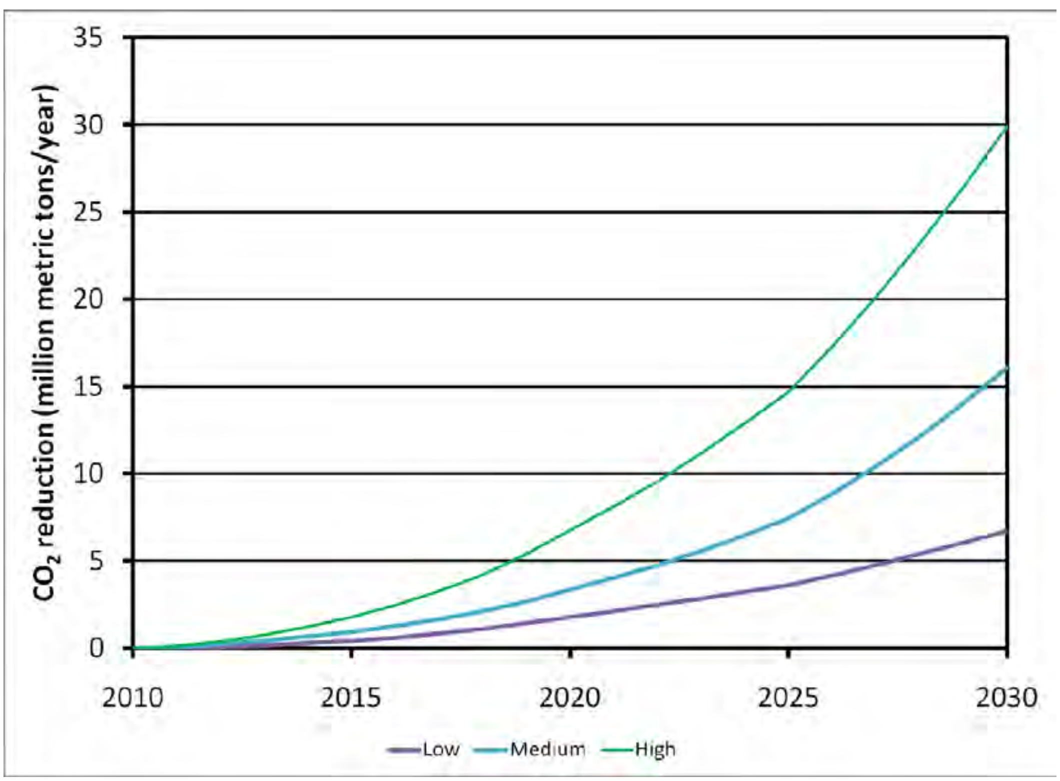

Figure 4-11
Estimated CO_2 reduction due to introduction of PEVs

Results for individual EV Project states

Figure 4-12 shows the expected PEV adoption rates in terms of new-vehicle sales for the medium scenario. Washington DC, California, and Oregon are expected to have the highest adoption, while Tennessee and Texas are the lowest of the EV Project area states.

Table 4-1 presents the new-vehicle adoption results in tabular form along with the penetration of PEVs into the overall vehicle fleet in each state.

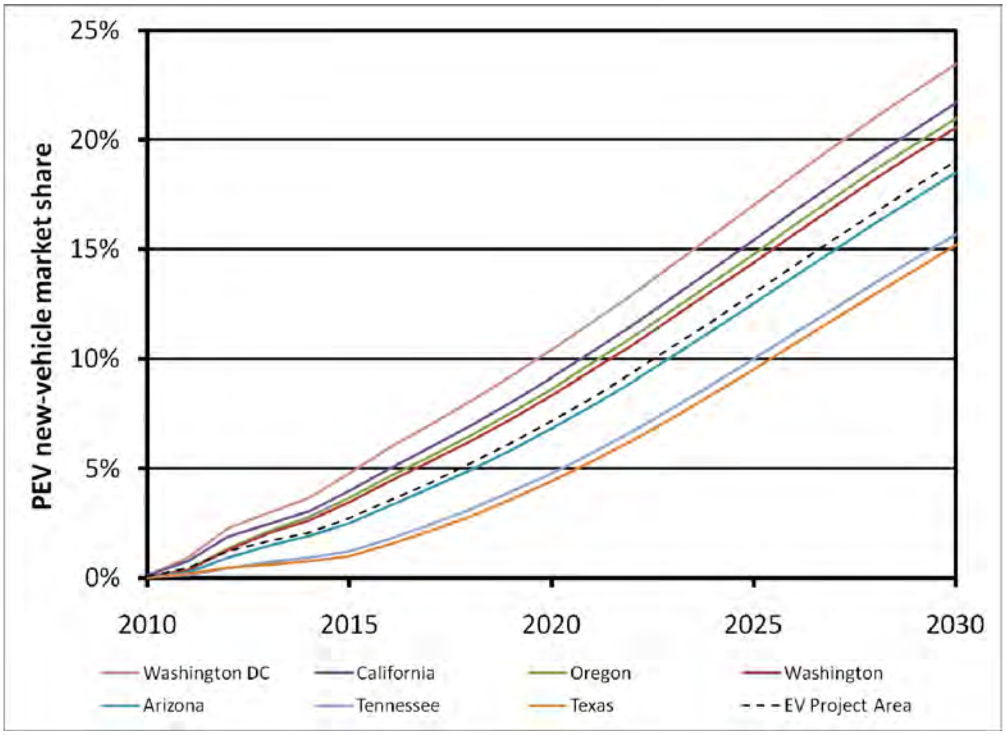

Figure 4-12
PEV adoption rates, Medium scenario, in EV Project area

Table 4-1
PEV market share and fleet penetration rates, Medium scenario, in EV Project area

State	PEV Market Share (percent of new vehicle sales)				PEV Penetration (percent of vehicles in service)			
	2015	2020	2025	2030	2015	2020	2025	2030
Washington	3.5	8.3	14.4	20.6	0.8	3.1	7.1	12.3
Oregon	3.7	8.6	14.8	21.0	0.9	3.3	7.3	12.5
California	4.0	9.1	15.4	21.7	1.0	3.3	7.3	12.4
Arizona	2.5	6.8	12.5	18.5	0.6	2.5	5.9	10.6
Texas	1.0	4.4	9.5	15.2	0.2	1.3	3.9	8.0
Tennessee	1.2	4.8	10.0	15.7	0.3	1.5	4.2	8.3
Wash. D.C.	4.8	10.4	17.0	23.4	1.2	4.1	8.8	14.6

The number of PEVs that enter the vehicle fleet in a particular state is equal to the new-vehicle PEV market share multiplied by the total number of vehicle sales (of all types) in the state. In general, states with more vehicles will also have more PEVs. Figure 4-13 shows the volume of PEVs in each state.

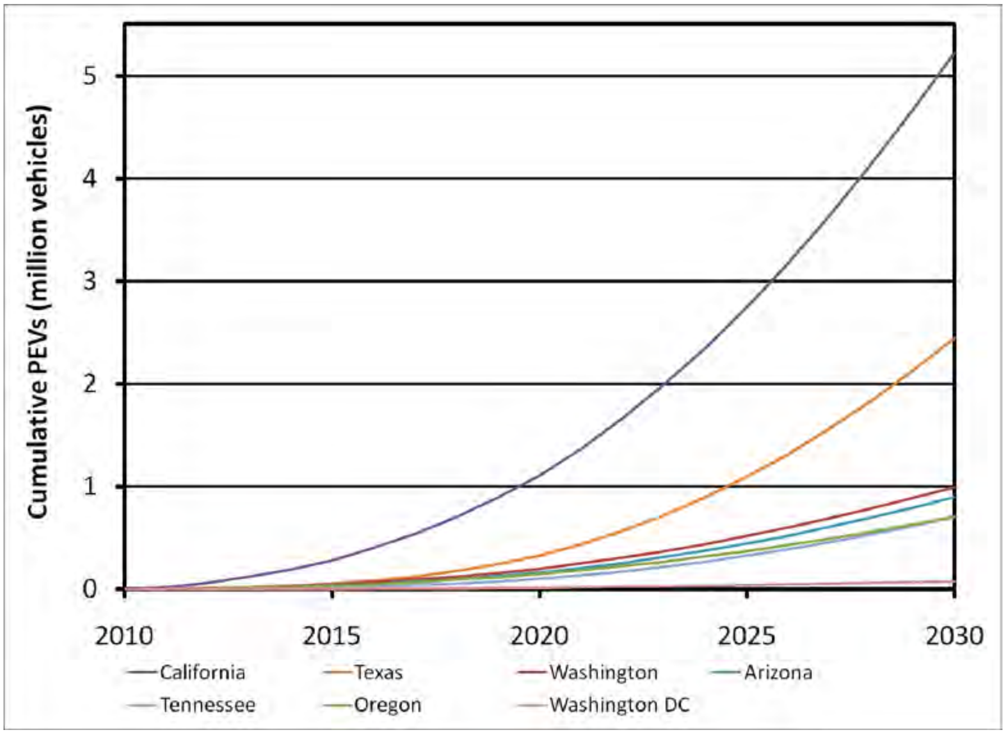

Figure 4-13
Cumulative PEV fleet, Medium scenario, in EV Project states

Texas

Although the PEV adoption rate in Texas is expected to be the lowest among the EV Project states, the large vehicle fleet in the state causes the forecasted number of PEVs to rank second among states in the EV Project area. Under the medium PEV adoption case used in this study, the number of PEVs in Texas is expected to reach approximately 330,000 by 2020 and 2.4 million by 2030.

The PEV electricity consumption in Texas, assuming the medium adoption scenario, would be about 1.0 TWh in 2020 and 5.7 TWh in 2030. Gasoline savings amount to over 80 million gallons in 2020 and just over 500 million gallons in 2030. The CO_2 reduction due to PEVs in Texas, using a forecast of CO_2 emissions of electricity delivery in the ERCOT region, would increase from 0.6 to 3.6 million metric tons between 2020 and 2030.

California

California is expected to have the highest number of PEVs of any state in the U.S. Based on the analysis assumptions for the medium scenario, the number of PEVs in California would grow to approximately 1.1 million in 2020 and then about 5.2 million by 2030.

Under the medium scenario, PEVs in California would consume about 2.6 TWh of electricity in 2020 and about 9.9 TWh in 2030. That fleet of PEVs would conserve about 230 million gallons of gasoline in 2020 and just under 870 million in 2030. The corresponding CO_2 reduction, based on the emissions of California electricity, would be about 1.6 million metric tons in 2020 and rise to about 6.2 million metric tons by 2030.

Section 5: Grid Impacts of Plug-In Electric Vehicles

This chapter uses PEV market adoptions forecasts and statistical driving patterns to develop estimates of system level demand from PEV charging and to understand potential impacts of PEVs on the distribution system.

Charging patterns

The timing of PEV charging can create either positive or negative impacts on electric generation and transmission systems. A significant amount of PEV charging coincident with the system peak would create a need for additional generation. On the other hand, charging performed consistently during off-peak hours could reduce system costs.

This section describes an analysis of passenger PEV charging at residential locations only. EPRI has projects underway to evaluate other vehicle types and other charging locations. At the transmission and generation levels, charging patterns will likely be correlated with statistical driving patterns. This study used the National Personal Transportation Survey (NPTS) as a source of driving data. The analysis considered three primary PEV charging scenarios to help bound the aggregate effects of PEV charging. Illustrations of other charging algorithms are also provided. The NPTS database reflects all car users and a mature market; new car buyers, commuters, and other early adopter segments of PEVs could have different driving patterns, which would cause different generation and transmission level impacts in the early years of the PEV market.

Uncontrolled charging

Vehicle home arrival is correlated with peak load, so it is often assumed that vehicle charging could create a large load coincident with the peak. However, vehicles will not all be connected at the exact same time. Figure 5-1 shows the distribution of home arrival times for an average American driver. Even during the peak hour of 5-6 PM, only about 12% of drivers arrive home during the hour.

Further analysis of this data by EPRI demonstrates that even without smart charging the load of vehicle charging is relatively well distributed. For example, Figure 5-2 shows a plausible high case for vehicle charging, which assumes that the fleet is made up of 30% Extended-Range Electric Vehicles (E-REVs), 50% blended PHEVs, and 20% EVs, all with 7.7 kW chargers which begin charging at full power immediately upon arriving at home. Since home arrival is coincident with other activities the load occurs on-peak, but vehicle charging has a maximum of about 0.7 kW per vehicle, and is relatively evenly distributed over about 6 hours. Other vehicle mixes which include more PHEVs or lower power chargers will decrease the vehicle charging peak and shift it later. Early customers may have a different driving distribution from the averages measured by the NPTS, and other factors may concentrate the load within a narrower timeframe. EPRI is continuing to study these factors in more detail to create the most accurate estimation possible.

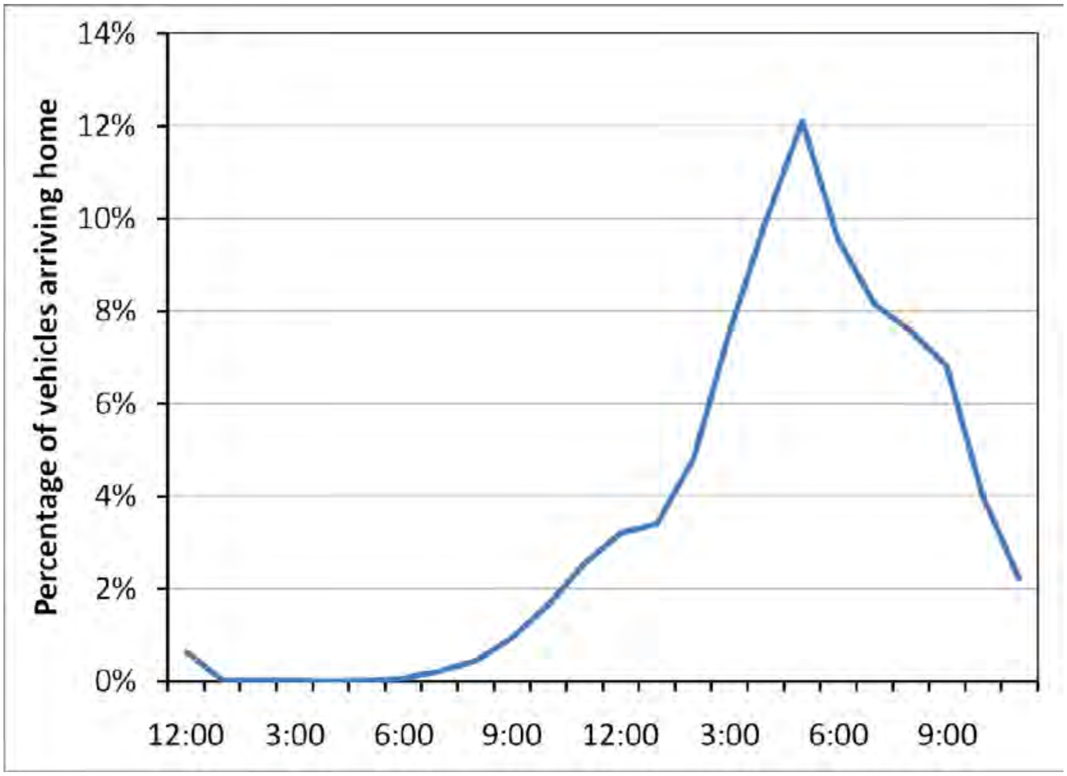

Figure 5-1
Home arrival time distribution

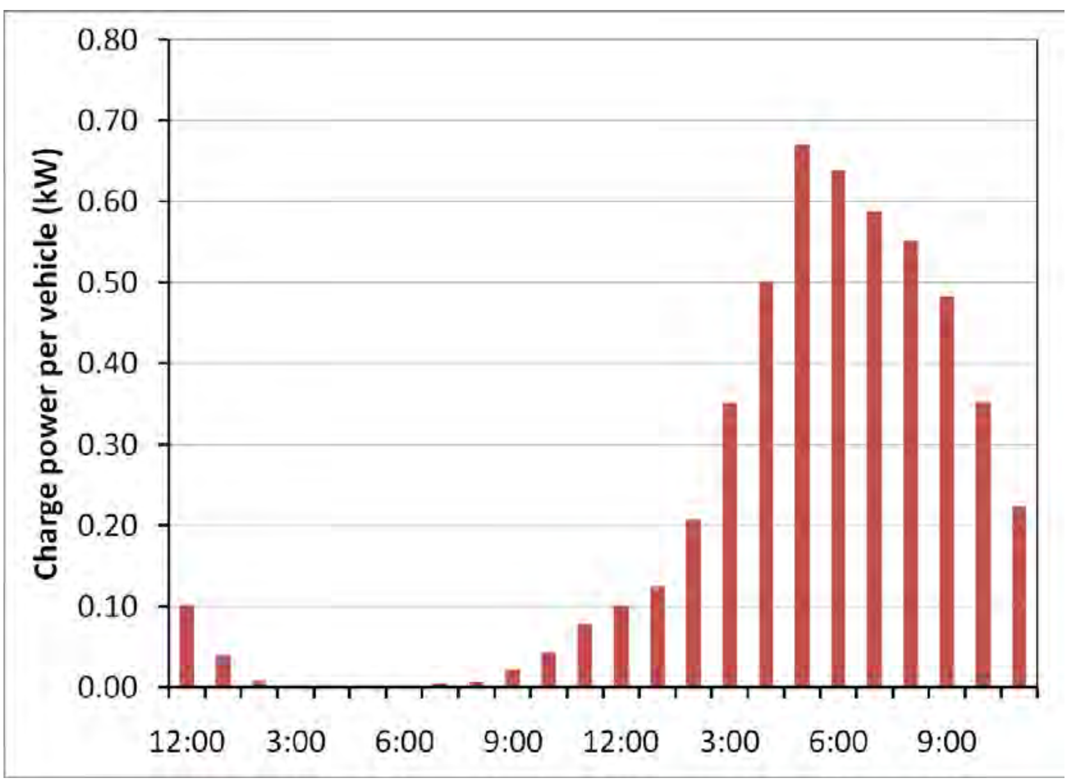

Figure 5-2
Uncontrolled vehicle charging

Managed off-peak charge control

It is possible to achieve any load shape with sophisticated control; various parties have proposed 'valley filling' strategies, 'renewable matching' strategies, and others. Figure 5-3 shows a control strategy which shifts the charge load to nighttime, but spreads it out relatively evenly over 6 hours. This can be accomplished by staging vehicles to start charging during one of 7 hours from 9PM to 3AM. The average per-vehicle load remains at about 0.7kW, but is now during a time which is more favorable for the generation system.

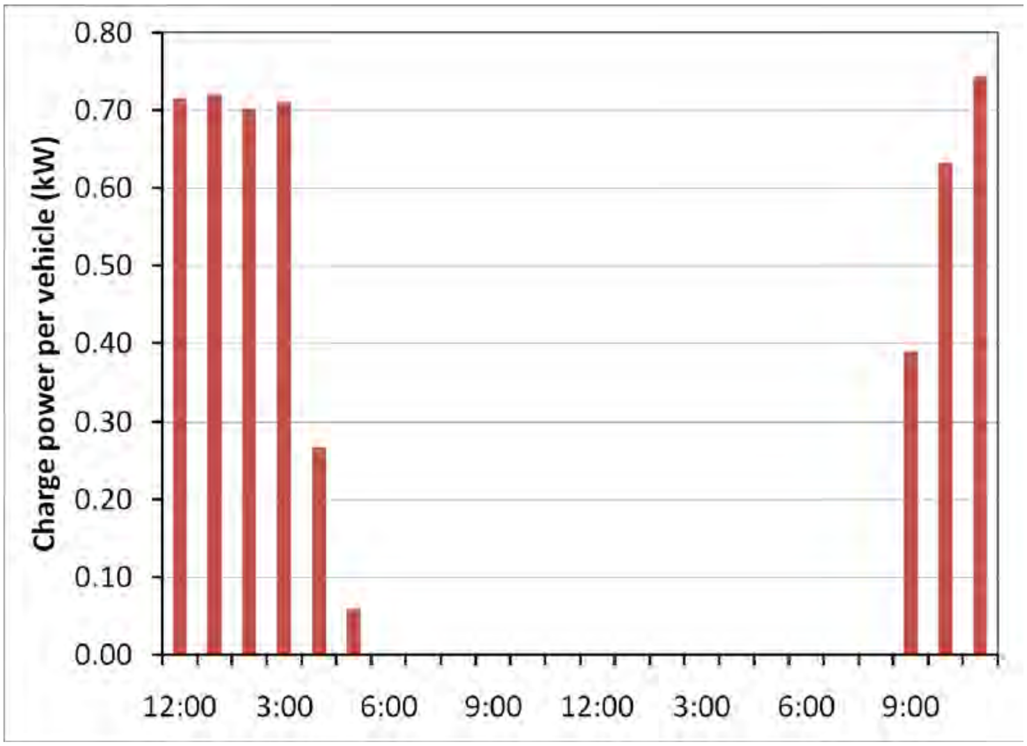

Figure 5-3
Vehicle load with managed off-peak charge control

Drawbacks of set-time charge control

Significant problems could be caused by ill-conceived charge control strategies. Figure 5-4 shows the cumulative percentage of vehicles which have arrived home at a given time, which indicates the potential for negative impacts. (Note that some vehicles never leave home, and are assumed to be at home from midnight on.) For instance, if vehicles were controlled with the algorithm "wait until 9PM and then turn on," (presumably with the assumption that this would move the load off of the peak), the load from charging could quickly ramp from no load to a high load, since about 73% of vehicles would be available to charge and had also been driven that day. Even though this load would be at the end of the system peak, this would present a very difficult control problem for utilities, even with a relatively small number of vehicles. Figure 5-5 shows the charge power profile in this case. The 3.5x difference between the 0.7kW 'uncontrolled' case and the 2.5kW 'set-time control' case illustrates the importance of achieving some level of control.

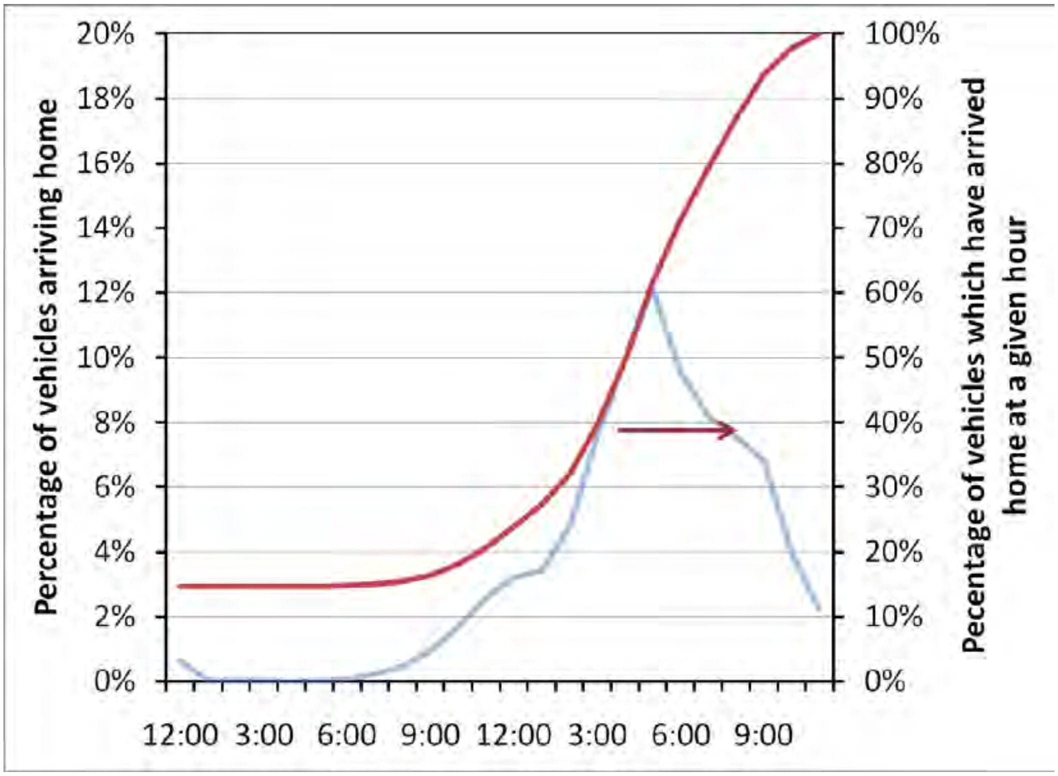

Figure 5-4
Vehicles already at home during a particular hour

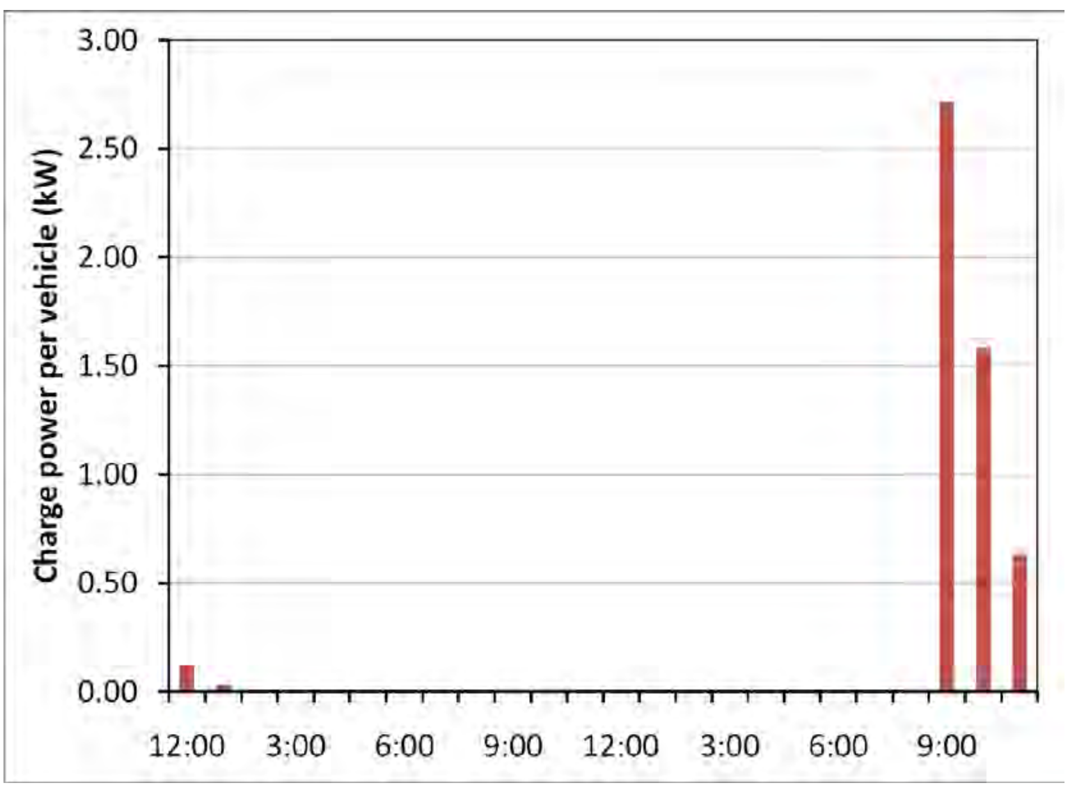

Figure 5-5
Electric vehicle charging demand using set-time scheduling

Charging load in the EV Project area

Figure 5-6 shows the PEV load in 2015 in the EV Project area for the three primary charging scenarios, assuming the Medium PEV adoption case. The PEV fleet consists of about 140,000 PHEV10 vehicles, 190,000 PHEV40's, and 190,000 EVs. The set-time charge control (Start at 9 PM) case has a significantly higher peak than the other cases, nearly reaching 1 GW at 9 PM, compared to about 380 MW at 2 AM for the "managed off-peak" case and just over 300 MW at 6 PM for the uncontrolled case. While the uncontrolled scenario is more likely to be aligned with the system peak, the load increases very rapidly under set-time control and would likely create an additional system peak.

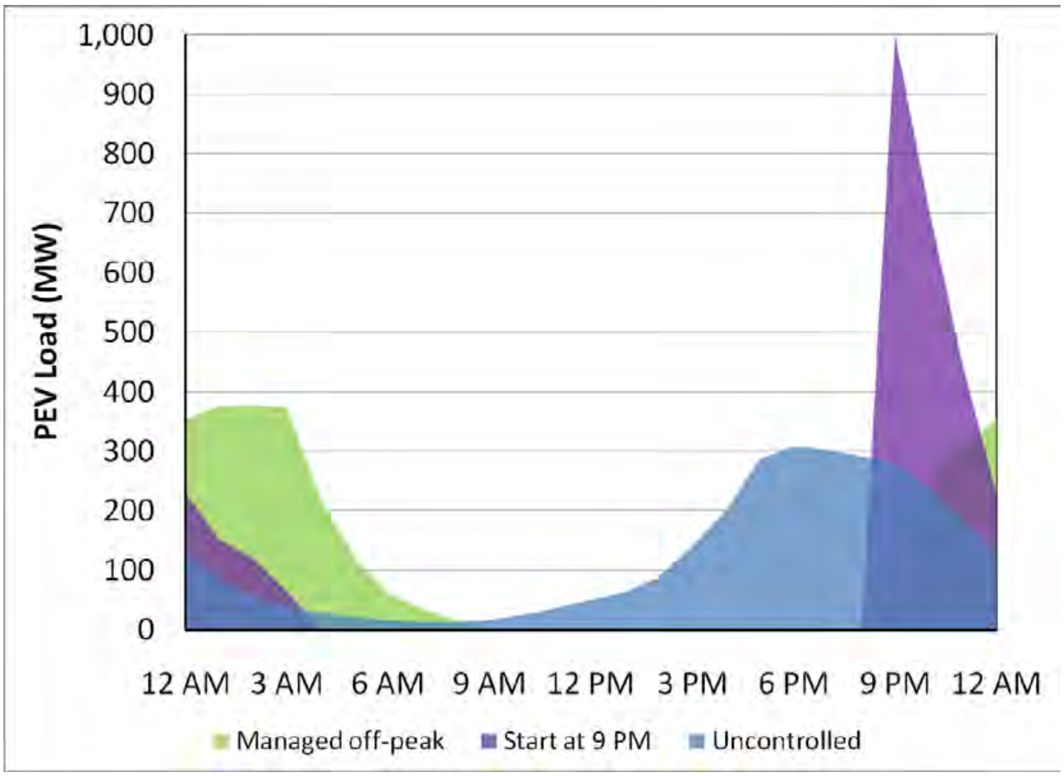

Figure 5-6
PEV charging load in EV Project area, Medium adoption scenario, 2015

Figure 5-7 illustrates the PEV charging load in 2030. The patterns are nearly identical in shape, but show significantly higher load. The PEV fleet under the Medium adoption scenario comprises 5.9 million PHEV10's, 3.0 million PHEV40's, and 3.0 million EVs. If the entire PEV fleet used set-time control, the charging load would be over 20 GW and would most likely create a new system peak and raise it significantly. Uncontrolled charging would most likely also cause the system peak to increase. The "managed off-peak" strategy would shift the significant new load into the off-peak hours.

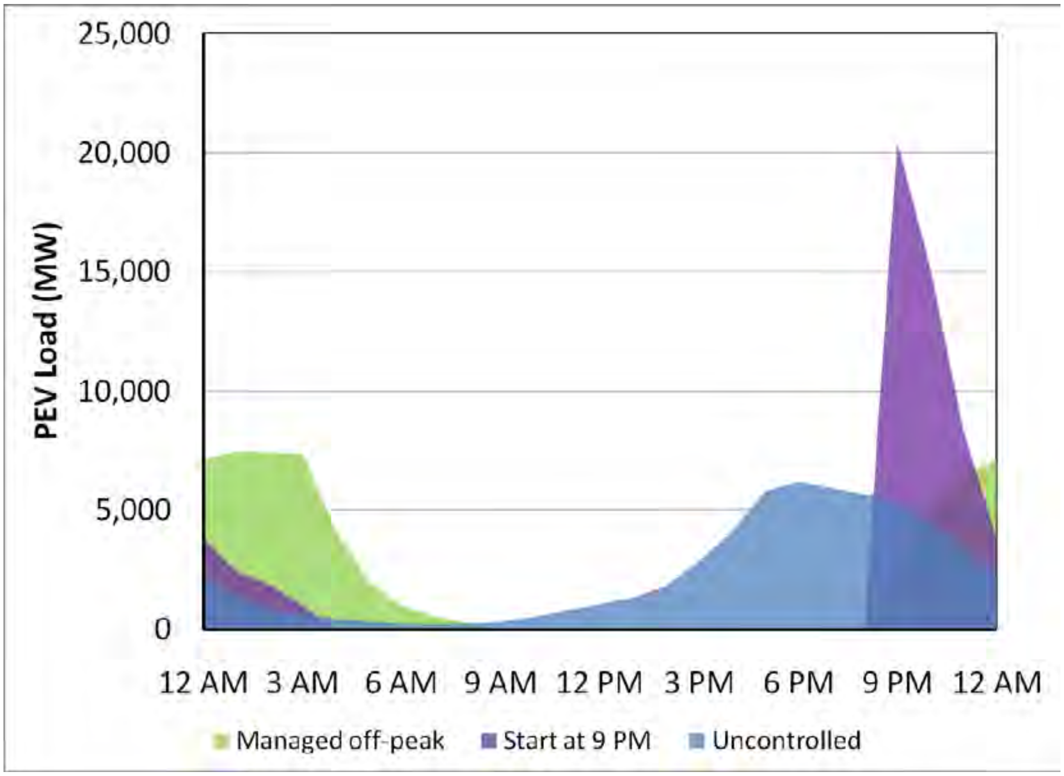

Figure 5-7
PEV charging load in EV Project area, Medium adoption scenario, 2030

Other charging algorithms

This section describes a preliminary analysis of two additional charging patterns. Many PEVs coming to market have facilities on-board to set the start time and/or end time of charging, which may include separate schedules for different days of the week. The Chevrolet Volt also allows the driver to enter a departure time and the utility's time-of-use rate schedule using the on-board system, and then configure the vehicle to seek a time frame that results in the lowest electricity cost. While Volt's "Rate & departure time" mode will likely provide benefit to PEV drivers, the effect on the utility is unclear. The aggregate charging load under this control strategy may be stacked against the start or end of the off-peak rate period, assuming that most drivers arrive and depart outside of the off-peak period and charging can be completed during the off-peak time frame. Further analysis of this charge algorithm is necessary.

Figure 5-8 illustrates the three strategies described earlier along with two other charging algorithms: "End by 6 AM" and "End by departure."

The "End by 6 AM" pattern represents a situation where the off-peak period ends at 6 AM and this charge completion time is acceptable to all vehicle users in the fleet. Under this scenario, the charging load has a peak at 6 AM that is higher than the "Start at 9 PM" peak because more vehicles are located at home during the "End by 6 AM" case.

The "End by departure" scenario assumes that the fleet of vehicles is configured to complete charging by differing times ranging between 5 AM and 9 AM, with the majority at 7 AM. This pattern may not be prevalent if the off-peak rate period ends before the departure time of most vehicles; in this situation the driver may be able to set the charge stop time to the end of the off-peak period, not the driver's departure time. Figure 5-8 shows that this algorithm spreads out the load and reduces the peak somewhat. However, the peak time may be undesirable with respect to the system load shape.

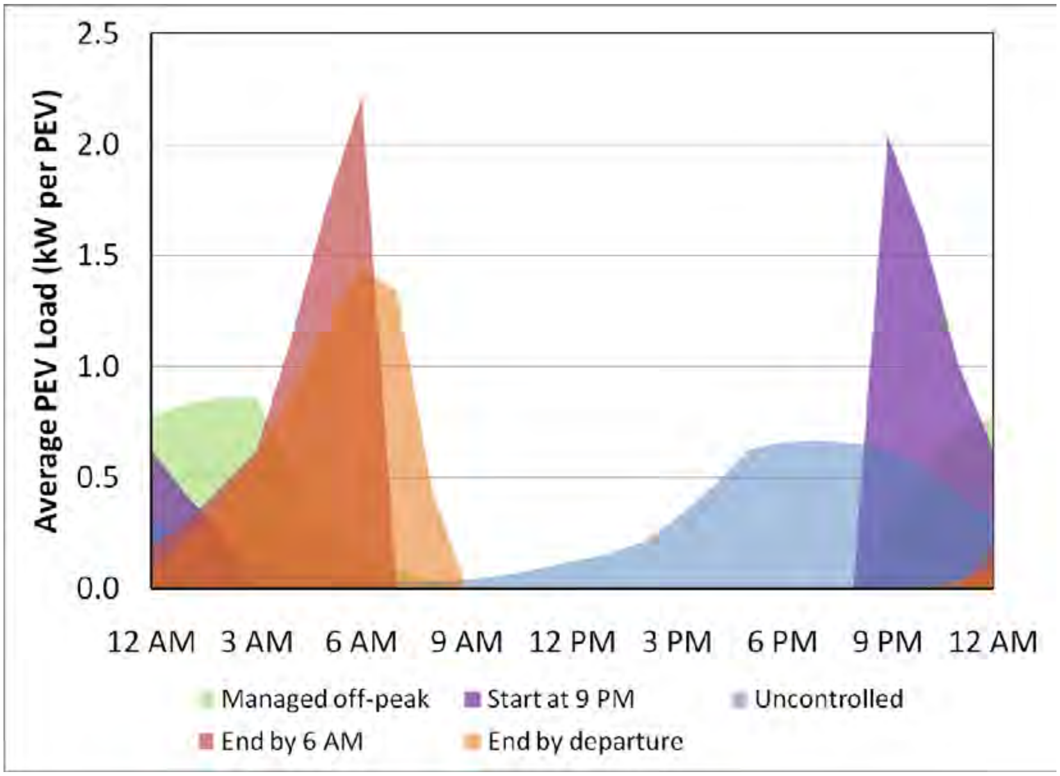

Figure 5-8
Other charging algorithms

Evaluations of Plug-In Electric Vehicle Distribution System Impacts

With plug-in electric vehicles poised to enter the automotive market this year, a remaining concern for electrical distribution utilities is how to account for these loads in their planning process. Seamless integration of PEVs to the grid is a critical step to encourage utility support for PEV commercialization. While technological barriers concerning PEVs continue to fall, the expected influence of PEVs on the electrical system has not been completely evaluated. Understanding the causes and relationships between this new load type and the distribution system will provide the ability for utilities to augment the planning process to account for any additional stresses to their systems.

In order to address this concern, an analysis methodology which accounts for PEV spatial and temporal diversities has been developed and used to study potential impacts on several representative circuits.

Electrification of the transportation sector has the potential to provide numerous societal and economic benefits. Some of the potential benefits include decreased greenhouse gas emissions, reduced dependence on imported petroleum, and a lower cost alternative to gasoline. However, adopting electricity as a "transportation fuel" may have significant impact on distribution circuits and distribution operations. Accounting for these impacts in utility planning and operations procedures is necessary for utilities to reliably supply this new load.

From a distribution planning perspective, the spatial and temporal variations of plug-in electric vehicles in terms of feeder loading, asset overloads, and aging across a distribution system are unknown. In order to accurately assess potential distribution systems impacts, these characteristic variations must be accounted for when performing system analyses.

Initial studies[16] mainly focused on the adequacy of generation to supply the increased load levels associated with increasing customer adoption of PEV. The overall ability of distribution networks to reliably supply this additional load was typically not considered nor was the influence of localized PEV concentrations, or clusters, on the system. Furthermore, these studies also concluded that the initial PEV demand could be contained within off-peak evening hours. However as system wide controls will be unavailable for the first generation of PEV, the actual demand will most likely be driven by customer behavior and therefore unlikely to be contained within off-peak evening hours.

EPRI has initiated a multi-year project to understand plug-in electric vehicle (PEV) impacts with several utilities in the United States, Canada, as well as a few European utilities. The purpose of the project is to identify, define, and calculate the impact of PEV on specific utility distribution systems. The basic premise of this project is to conduct a comprehensive evaluation of PEVs' influence on distribution systems operations using real distribution circuits and measured data.. In particular, dominant factors influencing PEV electrical characteristics as well as likely negative impact indicators are discussed.[17]

Initial findings concerning total additional feeder loading, asset overloads, and services transformer insulation aging are addressed in terms of PEV characteristics and circuit configuration[16]. Assuming a radial configuration, typical for most North American distribution circuits, the level of PEV load diversity experienced by each feeder asset will vary based on the number of customers served off that asset. For instance, substation equipment which serves large numbers of PEVs will benefit the most from diversity in the load characteristics while those assets closest to the point of PEV interconnection will experience the least diversity.

General Analysis Framework

The developed analytical framework is intended to evaluate the impacts of PEVs on distribution system thermal loading, voltage regulation, transformer loss of life, unbalance, losses, and harmonic distortion levels. These impacts are primarily determined by the assumed location of PEVs throughout the distribution network, when the PEVs are assumed to charge from the system, and the magnitude and duration of the charge cycle. In order to determine both system level impacts and individual component level impacts, the analysis framework provides for both deterministic and stochastic consideration of these key spatial and temporal variables. The study for which this analysis is conducted is based on a near-term PEV market penetration scenario representative of one to five years after PEV commercialization. Although the total PEV penetration is assumed to be small, possible high localized concentrations are possible. The study analysis framework utilizes known distribution system circuit information, PEV charge characteristics, and likely customer behaviors to construct models of likely system conditions. The general analysis framework is illustrated in Figure 5-9.

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[16] 1 M. K. Meyers, K. Schneider, R. Pratt, "Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional US Power Grids Part 1: Technical Analysis," Pacific Northwest National Laboratory, Nov 2007.

2 M. J. Scott, M. K. Meyers, D. B. Elliott, W. M. Warwick, "Impacts Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional US Power Grids Part 2: Economic Assessment," Pacific Northwest National Laboratory, Nov 2007.

3 S. W. Hadley, A. Tsvetkova, "Potential Impacts of Plug-in Hybrid Electric Vehicles on Regional Power Generation," ORNL/TM-2007/150, Jan 2008.

[17] J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall, Evaluation of the impact of PEV Loading on Distribution system operations, IEEE Power Engineering Society, Calgary, July, 2009

A. Maitra, K. Kook, J. Taylor, A. Giumento, Evaluation of PEV Loading on Hydro-Quebec's Distribution System Operations, EVS24, Stavanger, Norway May 13-16, 2009

J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall, Grid Impacts of Plug-in Electric Vehicles on Hydro Quebec Distribution System, IEEE PES T&D March 2010

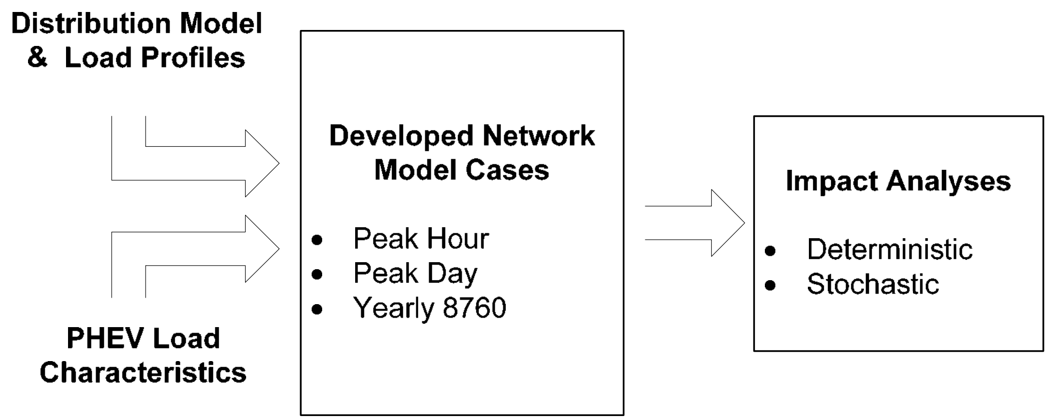

Figure 5-9
System Impact Analysis Framework

Distribution System Electrical Model

Evaluation of PEV loading impacts on the distribution system and specific components requires PEV load characteristics be considered relative to specific interconnection points in the electrical system. As such, complete electrical models of individual distribution feeders are developed from the substation down to individual customer meters including the substation transformer, 3-phase primary, laterals, distribution transformers, and secondary system up to service entrance.

In order to evaluate the potential impact of PEVs on distribution circuits of various types, multiple distribution feeders from multiple utilities are being studied. Circuits are being selected based on several factors including specific utility goals, connected customers and expected PEV penetration levels, and basic circuit characteristics.

All circuits are modeled in EPRI's open-source Distribution System Simulator (OpenDSS) analysis platform. OpenDSS is a comprehensive electrical power system simulation tool designed primarily for advanced analysis of distribution systems. OpenDSS is a multi-phase simulation tool that supports nearly all frequency domain analysis commonly performed on electric utility distribution systems. Additionally, OpenDSS has the ability to perform time domain analysis on the distribution system. Thus, sequential power flows can be simulated over successive time intervals (e.g., hourly) over a specified period of time with consideration of all circuit dynamic controls such as regulators and switch capacitors. This OpenDSS capability allows for direct consideration of interactions of the variations of PEV load patterns and daily and seasonal conventional load variations.

Generally, the basic circuit electrical model and customer load points are converted to the OpenDSS from the specific utility's distribution system analysis software format (CYMDIST, WindMil, SYNERGEE, FeederAll, etc.) Historical annual load profiles for primary distribution points (i.e., substation) and for typical customer classes served are utilized to assign load shapes for all customers in the model. The model is also augmented with other electrical data including station and distribution transformer data, secondary/service data, and capacitor and voltage regulator and associated control settings. Finally, any additional circuit metering (additional primary metering or AMI) is utilized to validate the circuit model. The validated electrical models then serve as the base case scenario against which the impacts of various PEV loading scenarios can be evaluated.

PEV Characteristics

PHEVs combine operational aspects of both battery electric vehicles (BEVs) and power-assist hybrid electric vehicles (HEVs). Similar to a BEV, a PHEV can store significant energy within an onboard battery for use during daily driving and recharge the battery from the electric grid. PHEVs, however, also have internal combustion engines that are used for propulsion when the battery is depleted, which will increase the near-term marketability of PHEVs relative to BEVs. From the perspective of the grid, BEVs will be the same as PHEVs, but will have larger batteries and will therefore charge for longer periods. While another potential use for PEVs is as distributed electrical sources, this functionality is not expected in the first generation of PEVs. Hence, the distribution impact analyses only consider loading characteristics of PEVs.

The developed framework considers the following principle factors that define PEV loading on distribution systems:

- Different PEV charge spectrums (battery type, charger efficiency) and profiles
- PEV market penetration levels per utility customer class (residential, commercial)
- Time profiles and likely customer charging habits
- Battery state of charge based on miles driven

Charge Profiles

PEVs are similar to existing hybrid electric vehicles (HEV) with the primary difference being the incorporation of an "energy" battery that allows the PEV to directly store grid electricity for propulsion. Thus, PEVs require a method of charging the battery on a regular basis. As proposed in SAE J1772, conductive charging is a method for connecting the electric power supply network to the PEV for the purpose of transferring energy to charge the battery. The conductive system architecture is suitable for use with electrical ratings as specified in Table 5-1. While PEV systems are still in development, likely electrical charge characteristics are being identified. SAE J1772 identifies three levels of charging based on voltage and power levels, as presented in Table 5-2

Table 5-1
Electrical Ratings (North America)

Charge Method	Nominal Voltage(Volts)	Max Current (Amps-continuous)	Circuit Breaker rating (Amps)
AC Level 1	120V, 1phase	12A/16A	15A/20A
AC Level 2	208-240V, 1phase	32A/80A	40A/100A

Table 5-2
PEV Charging Model Characteristics

Charging Levels	Voltage	Amps	Demand
AC Level 1	120 V AC	12-16 A	1.44-1.92 kW
AC Level 2	208 – 240 V AC	12 - 80 A	2.5 – 19.2 kW
DC Level 1	200-450V	<=80A	<=19.2KW
DC Level 2	200-450V	<=200A	<=90KW
DC Level 3	200 – 600 V DC	250, 350 & 400 A	<=240 kW

The PEV charge profile influences how the distribution system is impacted as it partially defines daily and annual PEV load shapes. One aspect of the study is to determine the extent to which the network is influenced by various charge profiles. The electrical demand over time, or charge profile, is defined by the battery size, charger efficiency, miles driven, and charge type. An example of how charge profiles vary over time is provided in Figure 5-10.

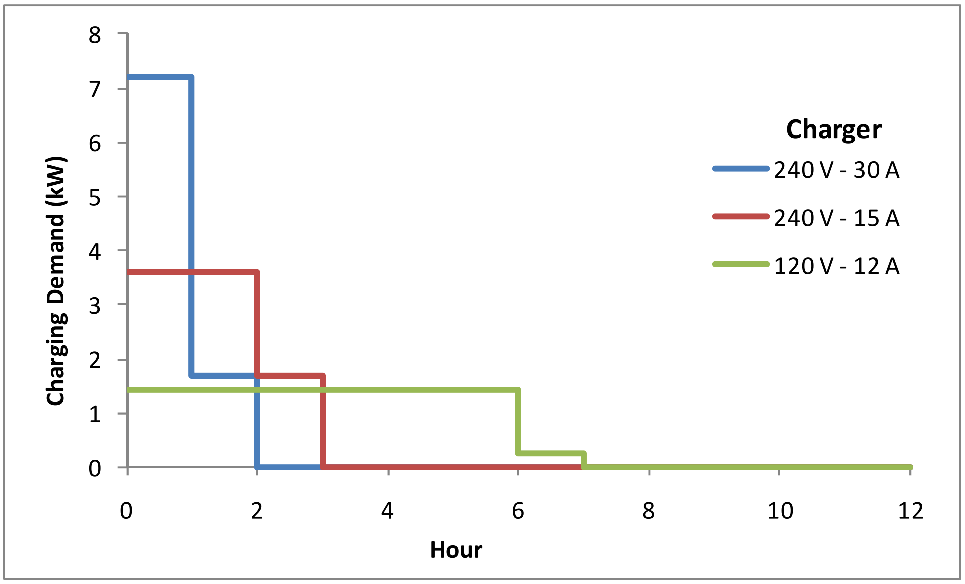

Figure 5-10
Full Charge Profiles 8 kWh Battery Pack (90% Efficiency)

Electric Vehicle Penetration Levels across Utility Customers

This study assumes that the entry of PEVs into the vehicle fleet takes future market share from both conventional vehicles (CVs) and HEVs. Market penetrations of CVs, HEVs, and PEVs from 2010 to 2030 are illustrated in Figure 5-11, with HEVs representing approximately 15% of the market of new vehicle sales when PEVs are expected to enter the market in 2010. As shown in this figure, PEVs could reach a maximum of 10% new vehicle market share by 2015 timeframe. PEV penetration levels in the study stochastic analysis are based on 2010 through 2015 projections -- 2% in a low PEV scenario, 4% in a medium PEV scenario, and 8% in a high PEV scenario. Penetration market levels ranging from 0 to 20% were considered for the system level deterministic evaluations.

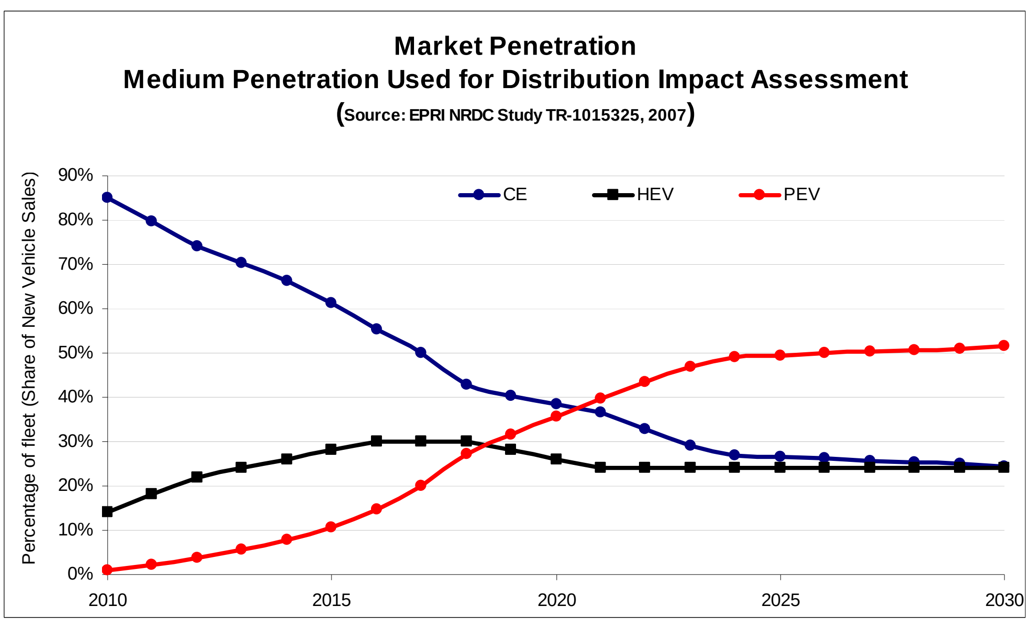

Figure 5-11
Projected New Vehicle Market Share Categories

Market Penetration / Residential Customer Adoption

As utility customers can have multiple vehicles, PEV market penetration levels must be translated into expected PEV penetration across utility customers. For each utilities service territory, Department of Transportation data concerning the number of existing vehicles per household are used to generate projections of the number of PEVs per utility customer as a function of market penetration, assuming that each utility customer corresponds with a household.

Recognizing market penetration as the probability that a vehicle is plug-in electric, *m,* the distribution for the number of PEVs out of *q* vehicles, the random variable *X*, is defined by the Binomial distribution as given in Equation 5-1.

$$b(x;q,m)=\begin{cases}\binom{n}{x}m^{x}(1-m)^{q-x} & x=0,1,\ldots,q\\ 0 & otherwise\end{cases}$$

Equation 5-1

Translation of market penetration into number of PEV per residential utility customer is based on the probability distribution $p(y)$ where Y is the discrete random variable for the number of vehicles per household. This probability distribution is derived from Department of Transportation statistics in the study region. Therefore, distribution for the random variable for the number of plug-in electric vehicles per residential customer, Z, can be found using Equation 5-2; where the variable k is the maximum number of vehicles considered for a single residence.

$$p(z)=\sum_{j=z}^{k}P(Y=j)*b(z;j,m)$$

Equation 5-2

Department of Transportation statistics for vehicles per residence for one example area is provided in Table 5-3. Using Equation 5-2, the probability distributions for number of PEVs per residential household are provided in Table 5-4 for three different penetration levels.

Table 5-3
Household Vehicle Ownership Statistics[18]

Vehicles Per Household				Total Household Vehicles	Total Households
0	1	2	3+		
28.7%	32.4%	28.0%	11.0%	9,743,069	7,735,264

Table 5-4
Probability Densities of PEV per Residential Customer for an Example Circuit

Market Penetration	PEV Per Household			
	0	1	2	3+
2%	97.70%	2.38%	0.02%	0.00%
4%	95.34%	4.66%	0.10%	0.00%
8%	90.77%	8.95%	0.37%	0.01%

[18]Journey to Work Trends: in the United States and its Major Metropolitan Areas 1960 - 2000, US Department of Transportation

Charge Times & Battery State of Charge

The modeled PEV demand is based on likely customer behavior. Likely customer charging behavior is derived from U.S. driving pattern data from the 2001 National Household Travel Survey (NHTS 2001)[19]. Assuming customers with no incentive to do otherwise will likely plug-in the vehicle when arriving at their residences, residential customer home arrival time data is used to generate PEV interconnection time probabilities. The resulting customer PEV charge time probability distribution used for the stochastic analysis is shown in Figure 5-12. Features of the dataset include:

- Analysis looks at a simple case; charging once per day at home, as soon as the driver arrives home
- This is the arrival time for the longest dwell time, and does not take into account arriving at home multiple times per day
- At any given time, a maximum of 12% of people are arriving home and will begin charging (the peak time is between 5:00 and 6:00 PM)
- People arrive at home throughout the day, although the highest rates of home arrival unsurprisingly occur during the peak hours for electricity use
- By 8:00 PM, 70% of drivers have arrived home
- Early morning arrival times coupled with long miles are unlikely
- Overall driving patterns - 74% of trips are less than 40 miles a day
- 14% probability that the vehicle is not driven that day is taken into account by the cumulative probability not reaching 100%.

Typical daily driving distances are also obtained from the National Household Travel Survey. For each possible home arrival time, a conditional probability is derived for the associated miles driven that day. Assuming a fixed depletion rate and battery size, the amount of energy required to recharge the battery is tied to the associated miles driven. Relationships between projected home arrival times and miles driven are represented in the study by the probability distribution shown in Figure 5-13.

[19] NHTS 2001 Unweighted Travel Day Data: Summary by Home Type, Purpose, End Time of the Last Trip, and Miles per Vehicle

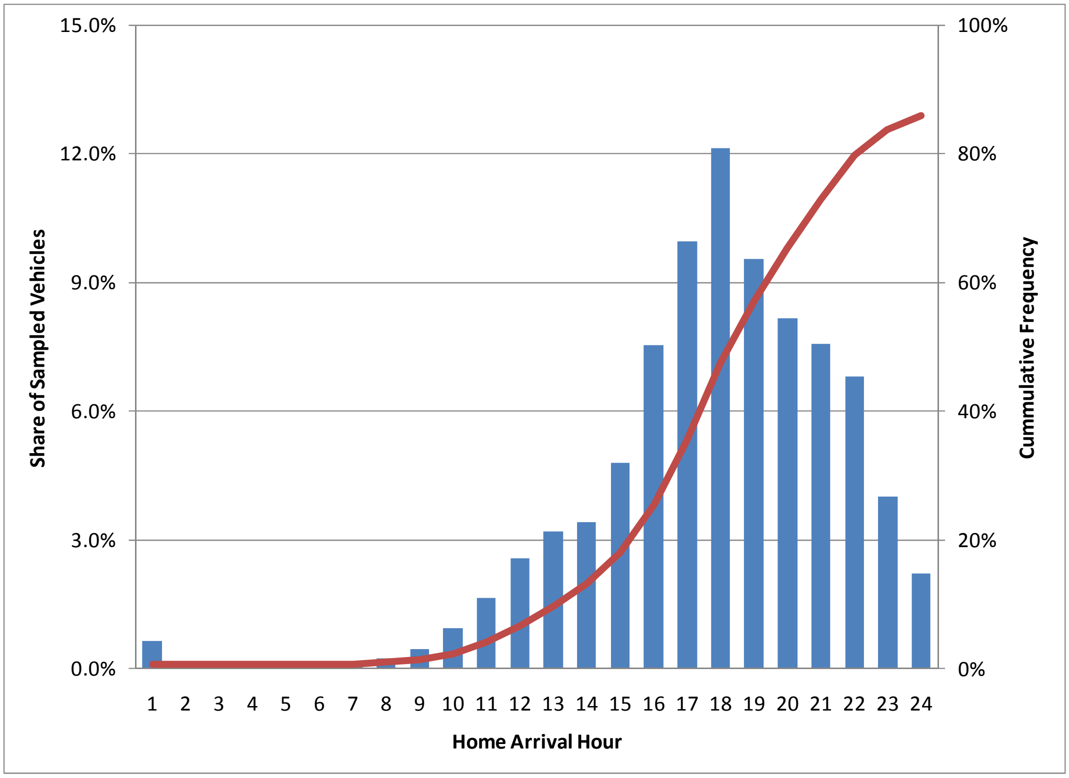

Figure 5-12
Example Profile of Home Arrival Time

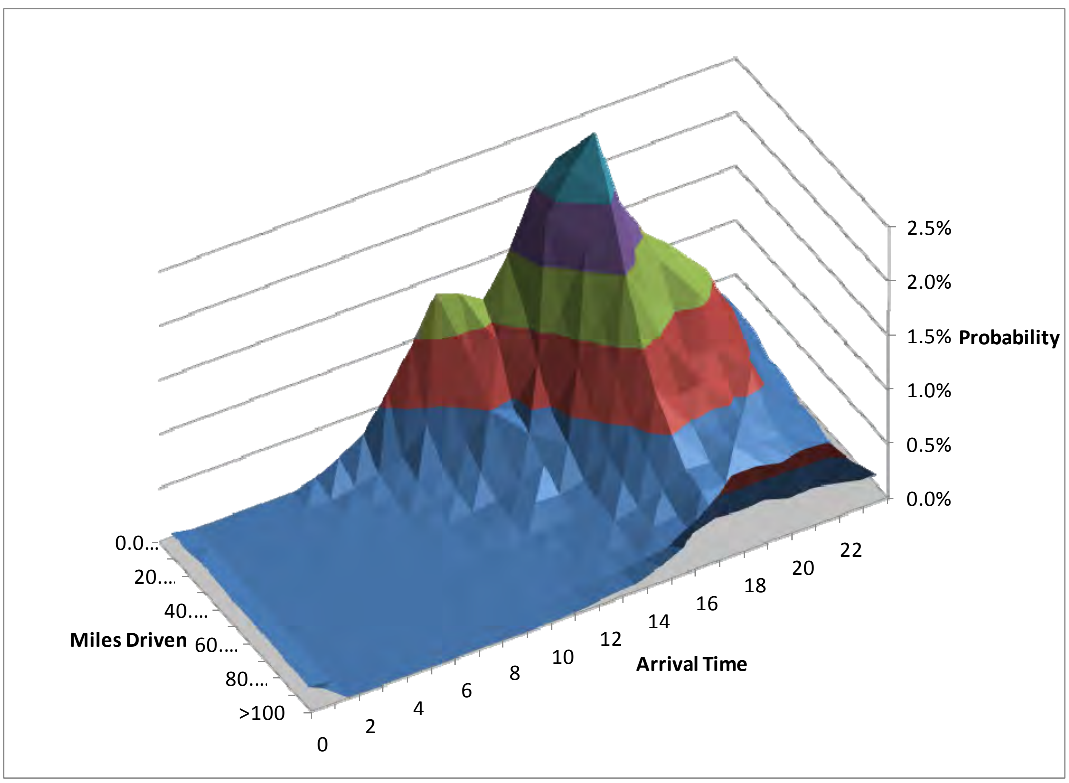

Figure 5-13
Conditional Miles Driven and Arrival Time Probabilities

System Impacts Assessment

Evaluated Impacts

The following PEV impacts are evaluated for various PEV characteristic combinations:

Thermal loading → to what extent are component normal and emergency ratings exceeded (number of occurrences, typically overload asset classes, duration and magnitudes)

Voltage → to what extent does PEV loading adversely impact system voltage regulation. (Voltage excursions, regulator operations, cap operations, etc.)

Unbalance → potential for disproportionate penetration on particular phase and results on system unbalance

Losses → impact on distribution system losses

Analysis Methodology

The study methodology was designed to capture potential near term distribution system impacts in response to customer adoption of the new load type. Assuming a near term planning horizon, only those characteristics expected from the majority of first generations of PEVs are considered. Specifically, PEV are modeled as simple loads whose characteristics are mainly dictated by customer behavior. Controlled dispatching or vehicle-to-grid operations of PEVs are not included in this evaluation. Additionally, growth in the base load is not included as no particular planning year is being evaluated in any given scenario. Finally, only residential customers are considered as possible locations of PEV interconnections, as initial adopters are expected to most likely charge at their residence.

As with any load, PEV demand exhibits its own unique diversity characteristics. In particular, PEV load diversity will be both spatial and temporal in nature; as every utility customer will not own a PEV nor will every PEV charge at the same point in time. Data detailing expected customer driving behaviors as well as PEV market projections are used to model the load diversity. The PEV characteristic data used in the study are outlined in more detail in Chapter 4. The three stage analysis, illustrated in Figure 5-14, was developed to fully evaluate effects on distribution circuits in light of these characteristics. Each analysis serves as a tool for examining system response from a different conditional perspective and used in conjunction provides a complete perspective of potential impacts. Specifically, the analysis identifies assets at risk of being impacted, and the likelihood and severity of impact.

- **Asset Deterministic Analysis** – Examined the ability of each asset to safely supply the worst-case projected load base. Existing capacity and number of customers serviced is determined using the circuit model and compared with the projected PEV load derived from probabilistic evaluations of PEV projections.
- **System Level Deterministic Analysis** – This provides qualitative sensitivity information on system wide behaviour to worst-case charging conditions at various penetration levels. Additionally, the analysis provides a quick evaluation of the boundaries for potential impacts to the system.
- **Stochastic Analysis –** Evaluated both the system as well as PEV charging across not only the full calendar year but hundreds of different spatial and temporal variations. The results of this analysis provide insights into impact likelihood and severity as well as information concerning the conditions under which these particular impacts occurred.

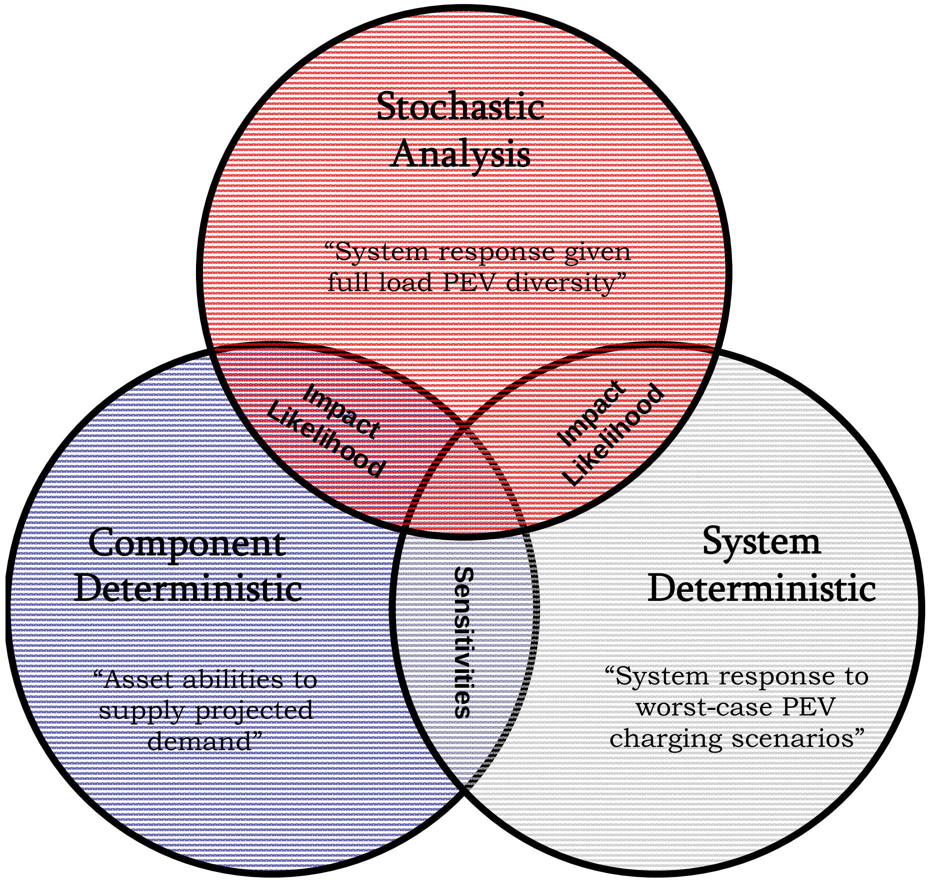

Figure 5-14
PEV Distribution Impact Evaluation Methodology

Component Deterministic

The Component Deterministic analysis stage identifies components or assets at risk of experiencing thermal overloads due to PEV adoption. Each asset's remaining capacity is compared to a conservative projection of the worst-case PEV demand that asset could experience. Assets with sufficient capacity to serve the projected demand are deemed highly unlikely to be impacted while the remaining assets are considered “at risk”. Note that the “at risk” classification does not mean an asset is likely to be impacted; instead, the possibility cannot be confidently ruled out. The likelihood of thermal overload occurrence is determined in the subsequent stochastic analysis.

The remaining capacity for every distribution feeder asset is derived from the circuit's peak hour load flow solution and asset thermal ratings. While the peak hour is typically used, evaluations could be performed for other hours of interest in a similar fashion. While the normal rating is used to calculate the remaining capacity of most assets, the emergency rating is typically selected for transformers due to their ability to handle higher loadings over equivalent periods of time.

Projected PEV demand is calculated using the probability distributions representing customer behavior and projected PEV market conditions. Furthermore, the projected demand must take into account the difference in demand due to the number of customers served off that asset. That is to say, an asset serving a single customer will not experience the same magnitude and spatial diversity of PEV load as an asset serving thousands of customers. Spatial diversity is incorporated into the projection through the number of PEV per household distribution defined earlier in Equation 5-2. As only a single point in time is considered, the probability that a PEV is charging during this period is simply represented by the probability *p*. The number of PEV charging at peak hour for a single residence, *C*, is then defined by Equation 5-3 In this study, 30% of the plug-in vehicles are assumed to charge during the peak hour. This assumption provides a conservative estimate of the temporal diversity based on analysis of the home arrival time and miles driven statistics.

$$p(c) = \sum_{j=c}^{k} P(Z = j) * \binom{j}{x} p^{c} (1-p)^{j-c} \qquad \text{Equation 5-3}$$

Equation 5-3 is the probability distribution that a single residence will have one or more charging PEVs. The distribution when considering n customers is determined by n-fold convolutions of $p(c)$, as shown in Equation 5-4.

$$p(c_n) = p_1(c) * p_2(c) * \ldots, * p_n(c) \qquad \text{Equation 5-4}$$

As such, every possible value of n requires it own probability distribution. To simplify the evaluation process, a discrete value $c_{n,max}$ is determined for every n such that Equation 5-5 is satisfied. This value represents the maximum number of charging PEVs for an asset serving n customers given P_{Lim} confidence. A high confidence value of 99.99% is assumed for P_{Lim} in this analysis.

$$\begin{aligned} &P(C_n \le c_{n,\max}) \ge P_{Lim} \\ &P(C_n \le (c_{n,\max}+1)) < P_{Lim} \end{aligned} \qquad \text{Equation 5-5}$$

The projected demand is then found by scaling $c_{n,max}$ by an assumed fixed value for individual PEV charger demands, S_{PEV}. A high value of S_{PEV} is typically assumed in order to retain the conservative nature of the projection. The worst-case projected demand, normalized by the number of customers served, can then be found using Equation 5-6.

$$S_{n,PEV} = \frac{C_{n,\max} * S_{PEV}}{n} \qquad \text{Equation 5-6}$$

At this point, the remaining capacity for an asset serving n customers can easily be compared to its projected worst case demand in Equation 5-6.

System Deterministic

The goal of the System Deterministic analysis is to capture feeder response to forced system-wide PEV penetration/charging scenarios. These deterministic scenarios are designed to identify system sensitivities to PEV characteristics in addition to system impact boundaries under increasing levels of penetration. The system deterministic analysis consists of 24-hour peak-day simulations of the full system model in OpenDSS with increasing PEV penetration levels from 0 to 20%. The PEV are randomly distributed throughout the system with locations remaining fixed as subsequently higher penetration levels are evaluated. While such high penetration levels are clearly unlikely, the analysis seeks to identify any particular system characteristics that may change nonlinearly with increased penetration.

Each allocated PEV is characterized by a full charge profile, each starting at the same point in time as well as with the same demand magnitude. The peak and off-peak hours are selected based on the measurement data for the peak day shown in Figure 5-15. In this study, 4:00 PM and 9:00 PM are selected to represent the peak and off-peak demand respectively.

Demand profiles are selected using 120V 12A and 240V 30A demand charger profiles assuming 8kWh of useable battery storage for each. While these scenarios do not represent likely scenarios, they provide indications of system sensitivities as well as response to worst-case conditions. Diversified charging scenarios are also introduced to provide a basic indication of how a "smart-charging" control scheme might alter or influence system impacts. Diversified charging scenarios are composed of staggered PEV interconnections that take place over a five hour period with 20% of the PEV interconnecting at each hour.

The following charge type and start time combinations:

- 120V 12A peak hour charging
- 120V 12A off-peak (75% peak) charging
- 120V 12A diversified charging
- 240V 30A peak hour charging
- 240V 30A off-peak (75% peak) charging
- 240V 30A diversified charging

Pea
k

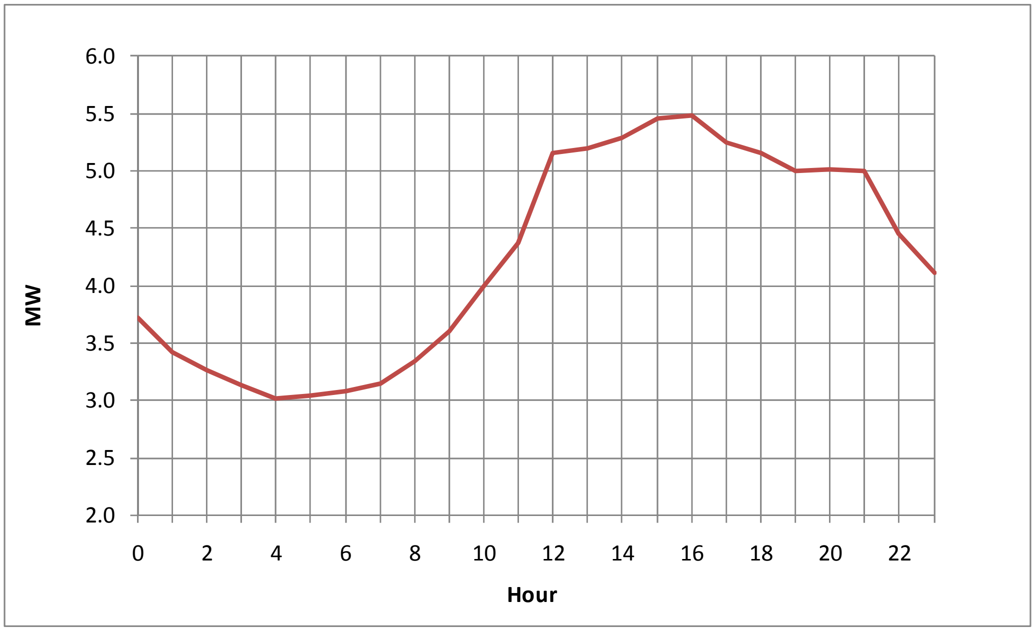

Figure 5-15
Example Peak Day Loading Profile

Stochastic Analysis

The stochastic analysis, outlined in Figure 5-16, is designed to assess likely impacts of PEV loading on the study circuit through full representation of PEV spatial and temporal diversity. The process uses the defined PEV probability distributions to assign PEV locations, types, and full calendar year charge profiles for one hundred randomly generated test cases.

The goal of this analysis is to provide the most reasonable projection of the impacts that are likely to occur under the assumed PEV penetrations. During the course of the analysis, this stochastic process is performed for low (2%), medium (4%), and high (8%) penetration levels.

Aggregation and post-processing of the results provide quantitative results, including system voltages, asset loading, system losses, and aggregate demands. The test case inputs and results are all retained through the analysis process such that specific conditions resulting in a particular impact can be tracked down and identified during the post-processing of the results. Additionally, impact results are statistically evaluated in conjunction with the network data to identify system conditions under which impacts are more likely to occur.

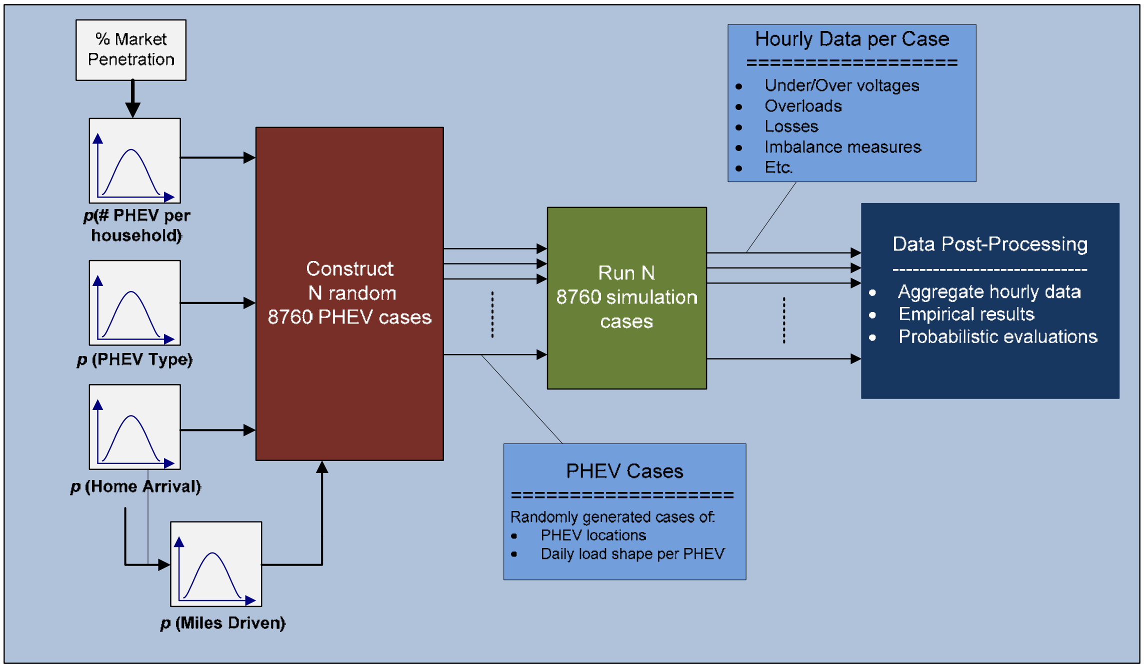

Figure 5-16
Stochastic Analysis Framework

PEV Characteristics and Clustering

EPRI's study targets distribution system loading impacts based on near-term projections (1-5 years) of PEV market penetration. The study does not consider PEV technologies that will not be available for the first generation of electric vehicles. In particular, PEVs acting as distributed generation and two-way communication controls are not evaluated. Hence, each modeled PEV is treated solely as a load whose behavior is determined solely by projected customer behaviors rather than external control settings.

Assessing PEV impacts on the distribution systems requires an accurate projection of the nature of the PEV loads. Fully representing these loads not only necessitates accounting for the electrical characteristics of the loads but the customer behavior that inherently dictates the PEV charging demand. A detailed explanation of the various PEV characteristics considered in this study is discussed in previous studies. [20]

In general the projected market penetrations considered in this study of PEV penetration levels were varied from 2-25%. Given the 1-5 year projection of the study, this range is expected to provide impacts for low to extremely high levels of projected market penetration. Still, even the "low" scenario is higher than that experienced with today's hybrid electric vehicles (HEV). While in some cases a high as steep as 25% penetration level is considered, 8% penetration rates are actually considered a more viable high estimation, given near-term projections.

It's important to note that even for low overall customer PEV adoption rates, PEV clusters can still occur. Based on system configuration and the assumed customer adoption probabilities, clusters will occur randomly throughout the system for each case. For example, PEV clusters are visible in the daisy plot shown in Figure 5-17. Each PEV is represented by the circle, and as PEVs are introduced at the same location they are spaced in a similar fashion as petals on a flower. Higher

[20] J. Taylor, A. Maitra, M. Alexander, D. Brooks, M. Duvall, Evaluation of the impact of PEV Loading on Distribution system operations, IEEE Power Engineering Society, Calgary, July, 2009

A. Maitra, K. Kook, J. Taylor, A. Giumento, Evaluation of PEV Loading on Hydro-Quebec's Distribution System Operations, EVS24, Stavanger, Norway May 13-16, 2009 penetration rates, of course, increase the potential for larger cluster sizes and more frequent occurrences. While PEV clustering may indicate an increased risk higher than average loading levels, PEV clustering alone does not signify the likelihood of negative impact occurrence as the other PEV load characteristics, and must also be taken into account.

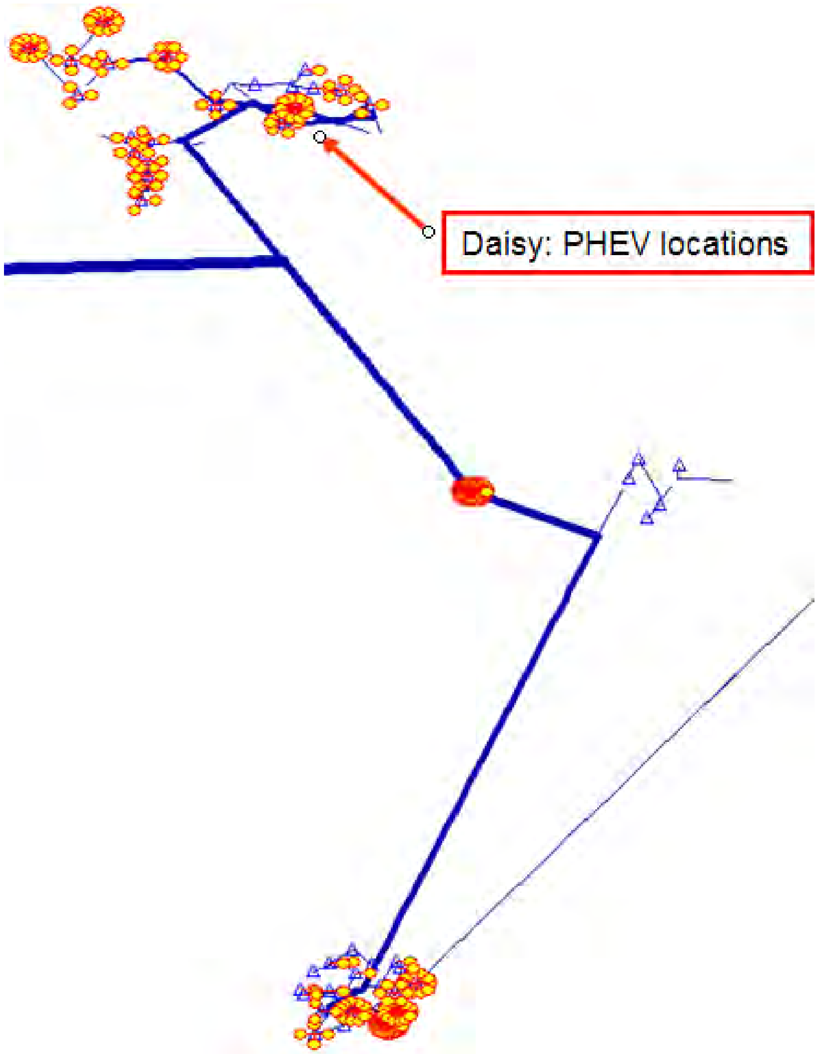

Figure 5-17
Example Daisy Plots Illustrating Clustering at 8% Penetration Levels

Given the radial configuration of most distribution circuits, the closer a circuit component is located to the loads the more likely it is to serve a PEV cluster. This relationship is illustrated in Figure 5-18 which shows the maximum occurring clusters sizes experienced by during the analyses. In this case, cluster sizes are expressed in terms of the ratio between PEVs per customer served. The higher ratio the higher the percentage of PEVs per customer served off that device. As shown, components serving fewer customers experienced higher relative cluster sizes. However, for devices serving large number of customer this PEV/customer ratio converges toward the original customer adoption rate in response to increased diversity in PEV spatial variations.

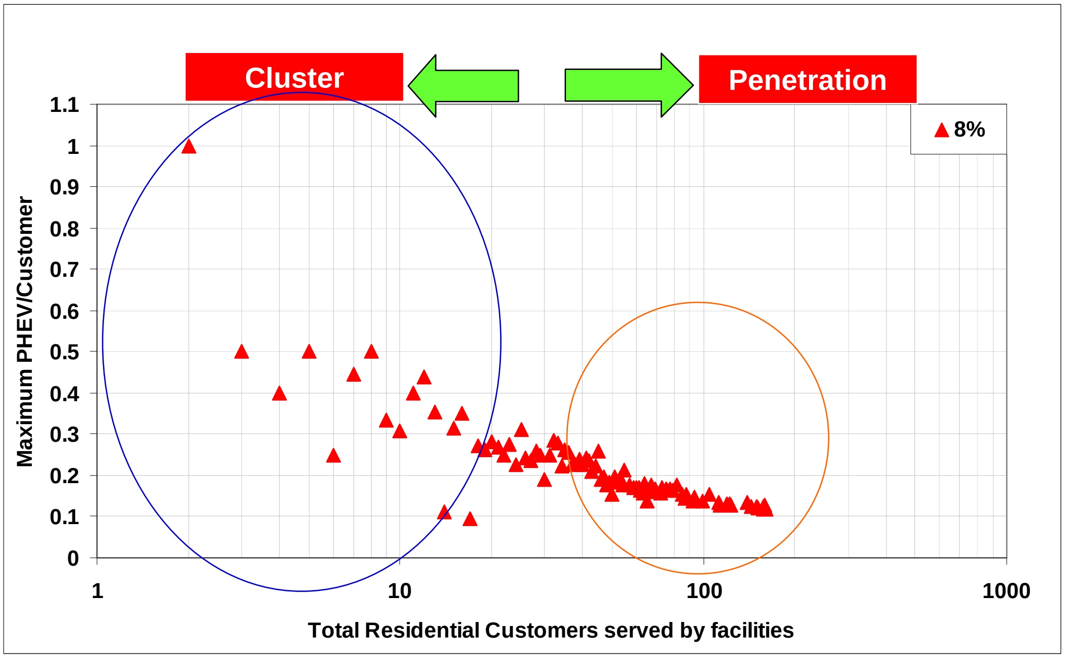

Figure 5-18
Relationship between Cluster Size and Customers Served

Aggregate Feeder Loading Analysis

Characterizing PEV load diversity's influence on the system is examined through the total additional loading expected to occur at the head of the feeder for each circuit. In analyzing the potential distribution impacts of electric vehicle charging a 'worst case' scenario will be needed to create a bound for the potential negative effects; however, it is important for this worst case to be plausible. There are uncertainties in the expected makeup of PEVs, different charging patterns served off each feeder, and customer habits, but these uncertainties can be reasonably bounded at the aggregate level as seen by the substation transformer.

At this level, charging patterns correlate more closely with statistical driving patterns. Driving pattern data from the National Household Transportation Survey (NHTS)[21] is used to represent likely charge times short of smart-charging incentives. For instance, potential interconnection hours were derived from the likely residential customer home arrival times shown in Figure 5-12. Vehicle home arrival is correlated with peak load, so it is often assumed that vehicle charging could create a large coincident peak. Still, vehicles will not all be connected at the exact same time. Even during the peak hour of 5:00 to 6:00 PM, only about 12% of drivers arrive home during the hour. It is also important to note that people do not necessarily drive far enough to completely discharge their cars.

By coupling these statistics with different customer daily driving distances patterns, known PEV types, electrical chargers characteristics, different profiles that can be used to control charging, the aggregate hourly demand as seen by the substation transformer, the aggregate hourly demand as seen by the substation transformer can be estimated.

Even without smart charging the load of vehicle charging is relatively well distributed. For example, Figure 5-19 shows a plausible high case for vehicle charging, which assumes that the fleet is made up of 30% Extended-Range Electric Vehicles (E-REVs), 50% blended PEVs, and 20% BEVs, all with 7.68 kW chargers which begin charging at full power immediately upon arriving at home. Since home arrival is coincident with other activities the load occurs on-peak, but vehicle charging has a maximum of about 0.7 kW per vehicle, and is relatively evenly distributed over

[21] Vyas, A, Wang, M., Santini, D., and Elgowainy, A., Analysis of the 2001 National Household Transportation Survey in support of the PHEV project to evaluate impacts on electricity generation and GHG emissions, unpublished information, 2009.

about six hours. Other vehicle mixes, which include more PHEVs or lower power chargers, will decrease the vehicle charging peak and shift it later. Similarly, EVs with higher power chargers will increase the vehicle charging peak, but the charging will finish sooner. Based on the study it was observed that for different vehicle mixes the aggregate on-peak load for a PEV will vary between 500-1100W per vehicle.

The total additional loading seen at the head of an example feeder is shown in Figure 5-20. The figure is derived using Monte Carlo analysis of the full PEV diversity model, and formatted future load growth can quickly calculated for multiple scenarios. In this projection, PEV demand peaks at 5:00 PM and averages to approximately 720 Watts per plug-in vehicle due to the diversity in the aggregate load. The additional demand expected at the head of the feeder can be found by scaling by number of vehicles representing each market penetration level and subsequent results being provided in Table 5-5. The importance of customer behavior is indicated by the demand profile's strong correlation with projected customer home arrival times. Overall, feeder load growth is expected to increase only slightly due to PEV adoption.

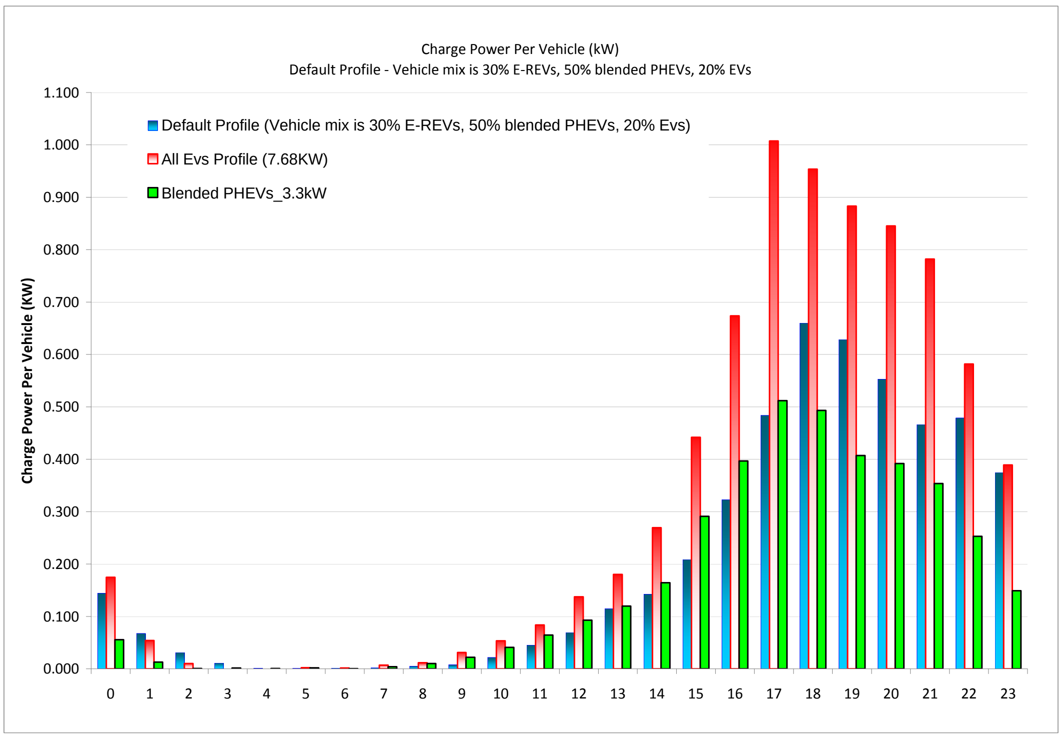

Figure 5-19
Aggregate Power Demand for Uncontrolled Vehicle Charging

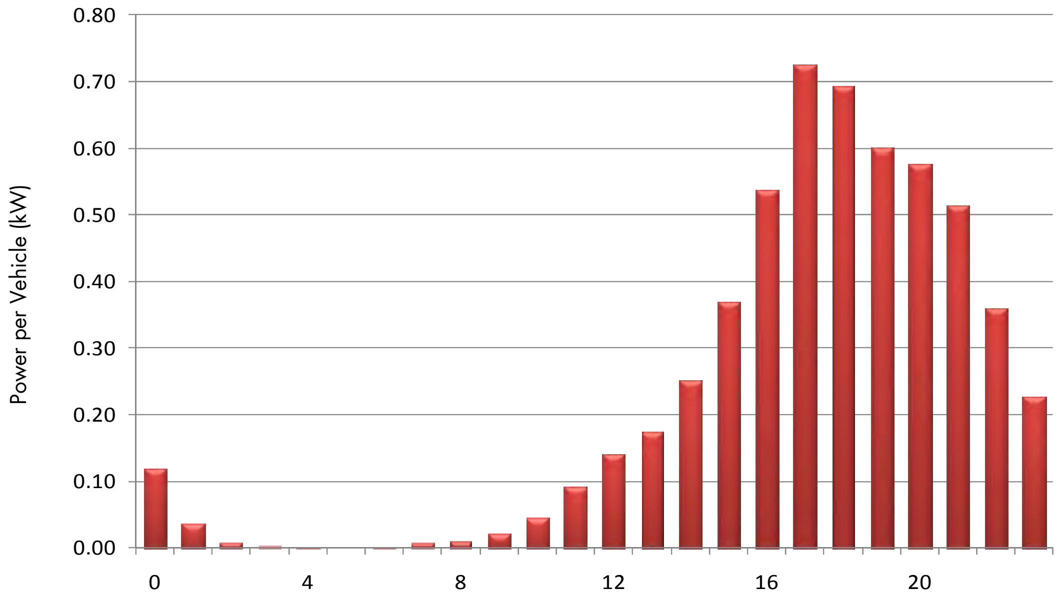

Figure 5-20
Average Hourly (Charge Power per Vehicle) Projected Plug-In Electric Vehicle Demand

Table 5-5
Projected Head of Feeder Average Demand Statistics

Market Penetration	Total Number Plug-in Vehicles	Peak PEV Demand (kW)	% Increase to Peak Demand
2%	34	24.5	0.5
4%	68	49.0	0.9
8%	136	98.6	1.8

Thermal Overloads

Identifying the extent to which particular distribution asset classes may be affected by PEV demand requires first examining how PEVs are expected to be distributed across the feeder. As PEV adoption occurs the locations of these loads are expected to vary with customer preference, which can appear random to the distribution engineer without some level of market acceptance data. This spatial variation in PEV demand across the feeder is not only determined by the aggregate PEV adoption rate but by the system design and configuration as well. As such, correlating expected PEV demand against the remaining capacity of each asset will provide a strong indicator of the number and type of assets most at risk from PEV adoption. Assets which are potentially at risk of exceeding their thermal ratings due to PEV adoption can be then identified by comparing their existing remaining capacity to the projected PEV demand. The peak hour remaining capacity for every distribution feeder component (asset) is determined from the peak hour load flow solution and each component's specified thermal ratings. While peak hour is typically examined, similar evaluations could be easily performed for other loading hours of interest.

The calculated peak hour remaining capacities for an example circuit are plotted in Figure 5-21 and Figure 5-22 as a function of the number of customers served from the component. Using the previously described Component Deterministic analysis, each asset is evaluated against projected PEV demands calculated and shown in Figure 5-21 and Figure 5-22. The remaining capacity of each asset is plotted as an individual point, and sorted based on customers served and asset class; while the projected demands are superimposed as lines for the three market penetration levels examined. Additionally, the estimated maximum PEV demand is also plotted permitting the quick identification of which assets are unlikely to be impacted and those which are at risk of impact. Each asset with a remaining capacity falling above the projected demand is unlikely to be impacted by 2%, 4%, and 20% PEV market penetration as shown in Figure 5-21 and Figure 5-22. Given the 99.99% value used for *Ptest* and the conservative construction of the maximum projected demand lines, the probability of exceeding the thermal ratings of these assets is less than 0.01%.

Intuitively, as PEV market penetration increases so does the potential for increased system impacts. As expected, the number of assets falling below the projected maximum PEV demand line increases as does the penetration level. More importantly for this system, the nature of the asset capacities in relation to the maximum PEV demand lines clearly indicate the impact from PEV adoption will most likely first appear on service transformers in particular. Not surprisingly, those transformers with the lowest kVA/customer capacity are the most susceptible. It is also interesting to note possibility of impacts from PEV clusters cannot be discounted even for penetrations as low as 2%.

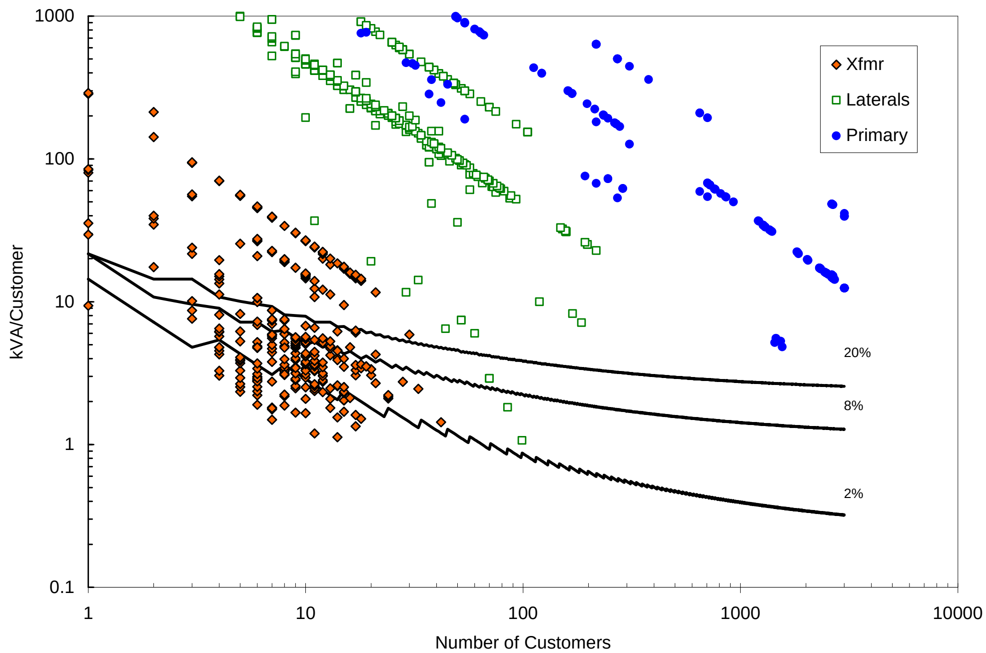

Figure 5-21
Feeder Asset Thermal Overload Risk Evaluation for 240V 30A PEV Charging

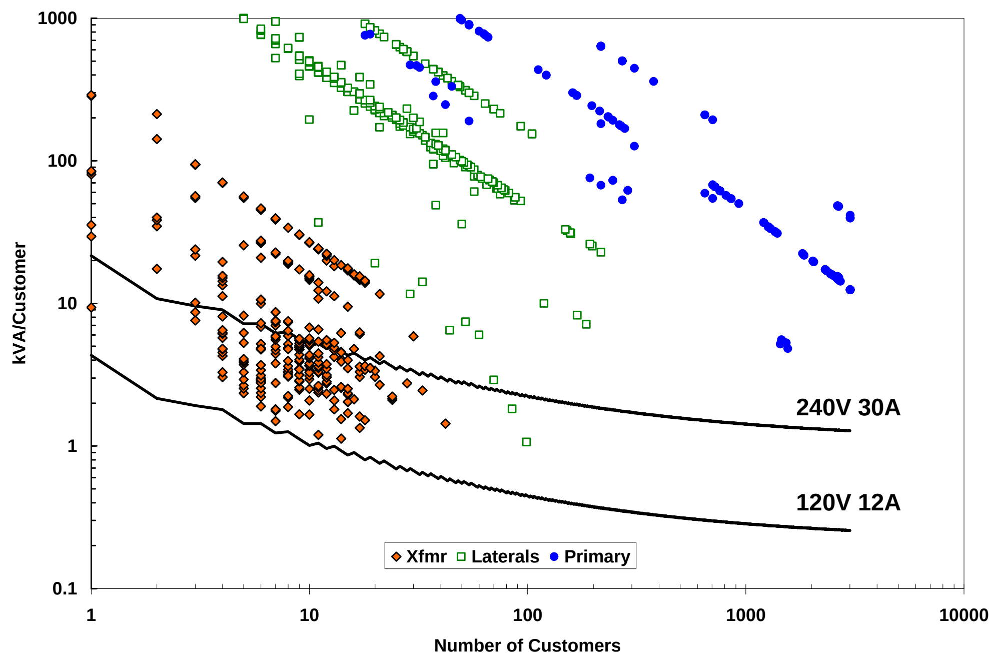

Figure 5-22
Service Transformer Overload Risk Evaluation 120V 12A & 240V 30A PEV Charging

It is also important to note that circuit model limitation may limit the accuracy of the projections. Specifically, circuit models based on allocation of customer load per transformer kVA do not capture innate variations in transformer loadings. As such, transformers that may be heavily loaded in the field cannot be completely discounted from being overloaded due to PEV charging. Nonetheless, recognizing the conservative nature of the projected demand, the conservative estimation of transformer thermal ratings, as well as transformer sizes typically installed on this circuit few, if any, thermal overloads are expected. Additional customer load data and further analysis is required to obtain a more accurate assessment.

It's important to restate that the developed asset evaluations do not identify assets that are likely to become overloaded. Rather, only those assets which are unlikely to be overloaded are identified given a particular PEV penetration level. The remaining assets are clarified as being at risk of exceeding their thermal rating. Assessing the likelihood of overload occurrence requires accounting for all diversity factors such as system load profiles, PEV charge behaviors, as well as temporal and spatial variations.

In the analysis, impact likelihood is determined through stochastic simulations of the circuit operation over a full calendar year for projected PEV penetration levels. In each case, PEVs of specific types are randomly assigned to customer locations according to defined PDFs. For each assigned PEV, an hourly demand profile for the full year is developed from the charge time and remaining charge PDFs. This process is repeated for each penetration level. The simulated results are aggregated across assets to provide an indication of impact likelihood. While thermal overloads are the only impact presented, the analysis examines other system impacts such as steady-state voltage changes and losses. Furthermore, the stochastic analyses are designed such that the particular system and PEV conditions resulting in a negative impact to the system or a particular asset can be identified.

The transformer overload results from the stochastic evaluations are provided in Table 5-6 for the example feeder. Selected results are presented in terms of the percentage of cases containing at least one overloaded as well as the average number of overloaded devices in these cases. Additionally, the total number of different transformers involved across all the cases is included to indicate the range of transformers potentially impacted. In general the results show that for this circuit only a few transformers are expected to exceed their thermal ratings at low penetration levels when PEV spatial and temporal diversity is represented. As expected, the average number of transformers likely to exceed their ratings in each case increases at the higher market penetration. Furthermore, the number of transformer at risk also increases which agrees with the previous asset evaluations shown in Figure 5-21. Furthermore, while a large number of transformers are at risk for both penetration levels it is unlikely that a large percentage of these will be impacted.

Table 5-6
Thermal Overload Cases and Overload per Case Average

	2%			8%		
Size	**% Cases**	**Avg # of Overloads**	**Xfmr @ Risk**	**% Cases**	**Avg # of Overloads**	**Xfmr @ Risk**
25 kVA	94%	1.71	26	99%	6.34	38
37.5 kVA	37%	1.05	4	86%	1.45	11
50 kVA	70%	1.00	12	96%	3.21	23

Statistics for some of the conditions under which the transformer overloads occurred are provided in Table 5-7 for the 2% penetration case. These statistics summarize the transformer peak hour loading in the base case, number of customers served, and number of assigned PEVs recorded for each transformer overload. The most noticeable feature is that the transformers overloaded in the evaluations tended on average to be loaded well past nameplate rating before any PEVs are connected. As the thermal overload rating for this circuit is specified as 130%, it can be reasoned that the majority of the overloads occurred on transformers with an existing load levels close to their thermal limit. This is also reflected by the low number of PEVs assigned on average which resulted in an overloaded condition. Additionally, the number of customers served by each overloaded transformer appears to be high on average. This high number of customers served not only correlates with the higher loading levels but signifies a higher chance that one or more customer loads are assigned PEVs in the evaluations. The importance of existing load levels and number of customers served is not unexpected as they were utilized in the asset capacity analysis of the previous section to denote the existing capacity per customer. Hence, the most likely transformers to be impacted are those with low capacity per customer margins.

Table 5-7
Transformer Thermal Overload Conditions Statistics (2% Penetration)

kVA	**Number Customers**			**Base Peak Loading (% of Rated kVA)**			**PEV**		
	Max	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
25	11	6.7	4	129.9	120.4	98.7	3	1.2	1
37.5	14	12.8	6	129.9	127.3	113.5	2	1.2	1
50	18	14.2	8	129.7	125.6	104.3	3	1.3	1

These factors remain unchanged when considering the higher 8% penetration level as shown in Table 5-8. While the minimum transformer loading does decrease, signifying more impact from of larger PEV clusters, the average loading and customers served does not change dramatically. Therefore under these conditions, the transformers with lowest kVA/customer remaining capacities are simply more likely to be overloaded which accounts for higher average number of overloads per case results in Table 5-6.

Table 5-8
Transformer Thermal Overload Conditions Statistics (8% Penetration)

kVA	Number Customers			Base Peak Loading (% of Rated kVA)			PEV		
	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
25	11	6.7	4	129.9	118.3	91.3	6	1.8	1
37.5	14	12.2	6	129.9	124.8	95.8	6	2.4	1
50	18	14.2	6	129.7	123.7	101.3	6	2.8	1

As design practices varies between utilities as well as specific operating condition between circuits, the actual level of thermal overload impacts is circuit dependent. However in general, assets with low capacities per customer are the most likely to be impacted by customer adoption of PEVs. This is especially true for those assets, such as service transformers, which do not benefit as greatly from PEV load diversity.

Steady-State Voltage

Vehicle charging is not expected to significantly impact primary voltages based on the results that we have observed from about 40 utility circuits. The minimum daily voltages observed for an example circuit are plotted in Figure 5-23 and provide boundaries of what the worst-case voltage impacts would be. For instance, the 240V 30A peak hour worst-case results in more than 2% voltage drop at 8% market penetration. As shown in the feeder's voltage profiles (Phase A-red, Phase B-blue, Phase C-green) for both cases, Figure 5-24, the additional voltage drop in this case lowers the primary voltages on the primary below the favorable 117 V but above the tolerable 114 V limit. Nonetheless, this particular worst-case boundary point is fairly extreme and the actually additional voltage drop is expected to much lower when the full load diversity is taken into account. This is illustrated by insignificant levels of voltage drop for the other charging profiles, except at unrealistically high penetration levels. Overall, near-term PEV demand is not expected to significantly decrease primary voltages below tolerable levels

In the analysis, voltages are calculated across the entire circuit down to the secondary side of each service transformer. Cases where secondary lines, which are not included in the model, are nearly or already experiencing voltage issues, will be further aggravated by additional PEV demand. These cases are true for every distribution feeder experiencing any type of unexpected per capita increase in load and are usually handled by the utility on a case by case basis. Nevertheless, such cases are not necessarily expected to be widespread across the feeder at the projected penetration levels.

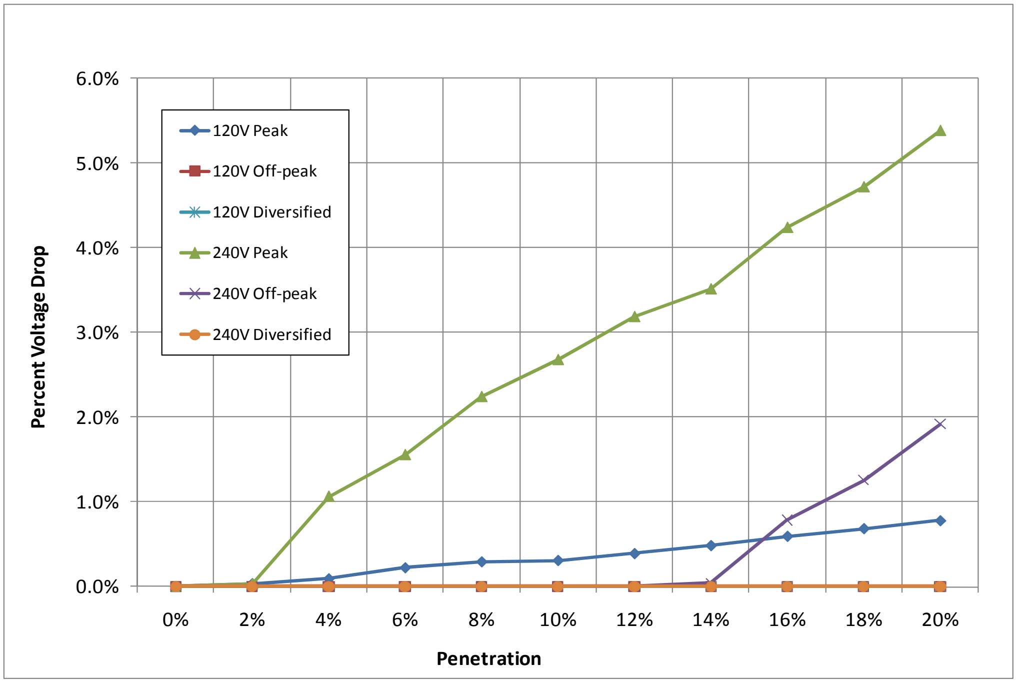

Figure 5-23
System Deterministic Minimum Transformer Secondary Voltages

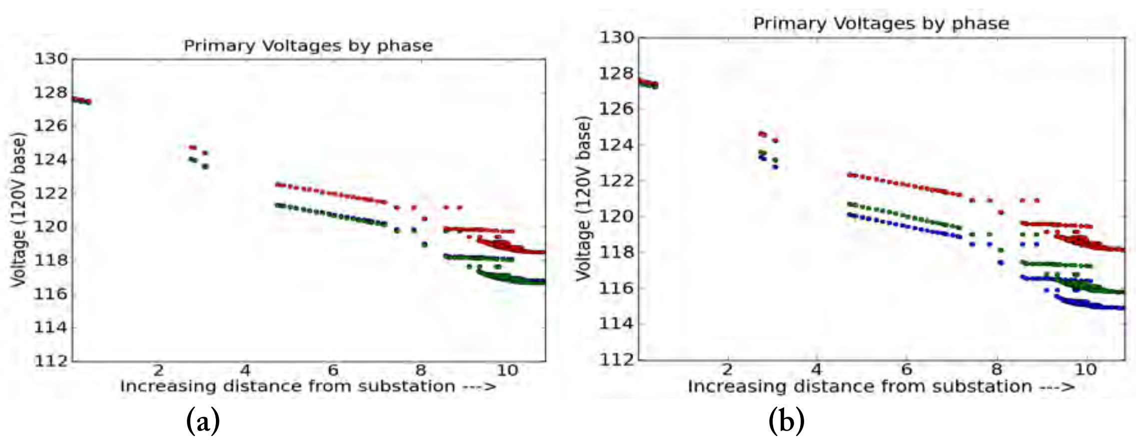

Figure 5-24
Feeder Peak-Hour Voltage Profiles (a) Base Case (b) 8% Market Worst-case

Voltage Unbalance

Unbalanced voltage conditions can result in motor damage due to excess heat. ANSI standard C84.1-1995 sets the maximum no-load voltage unbalance at the meter to 3%. Still, both NEMA and the IEC recommend motors should be derated at higher than 2% unbalance. The voltage unbalance factor (VUF), percent ratio between the negative and positive sequence voltages, was calculated based on the modeled voltages at the tie point location. The results from an example circuit, plotted in Figure 5-25, show the modeled voltage unbalance to fall with acceptable ranges even under worst-case conditions.

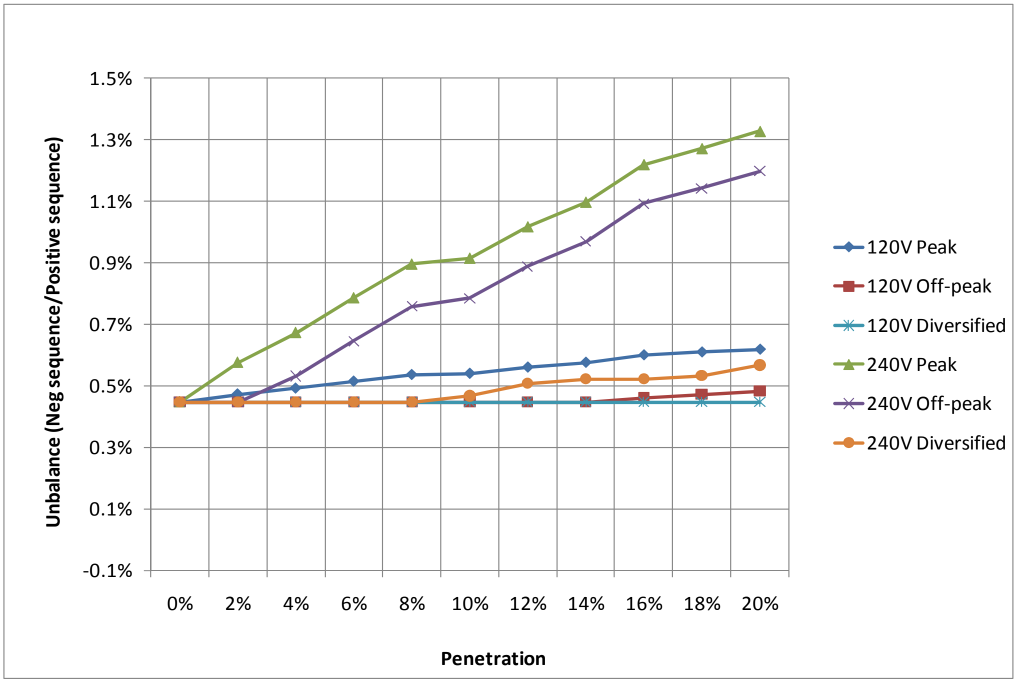

Figure 5-25
System Deterministic Case Voltage Unbalance Factors

Network Losses

PEV adoption is not expected to significantly impact system losses. Total losses incurred during the simulated peak day, for an example circuit, are given in Figure 5-26. Only a minor increase in losses is shown to occur for the different charging scenarios with the diversified and slower charging scenarios providing the lowest increase to total losses. This is not unexpected; these scenarios tend to shift most of the charging to hours where base demand is lower, thus providing lower percent copper or no-load losses.

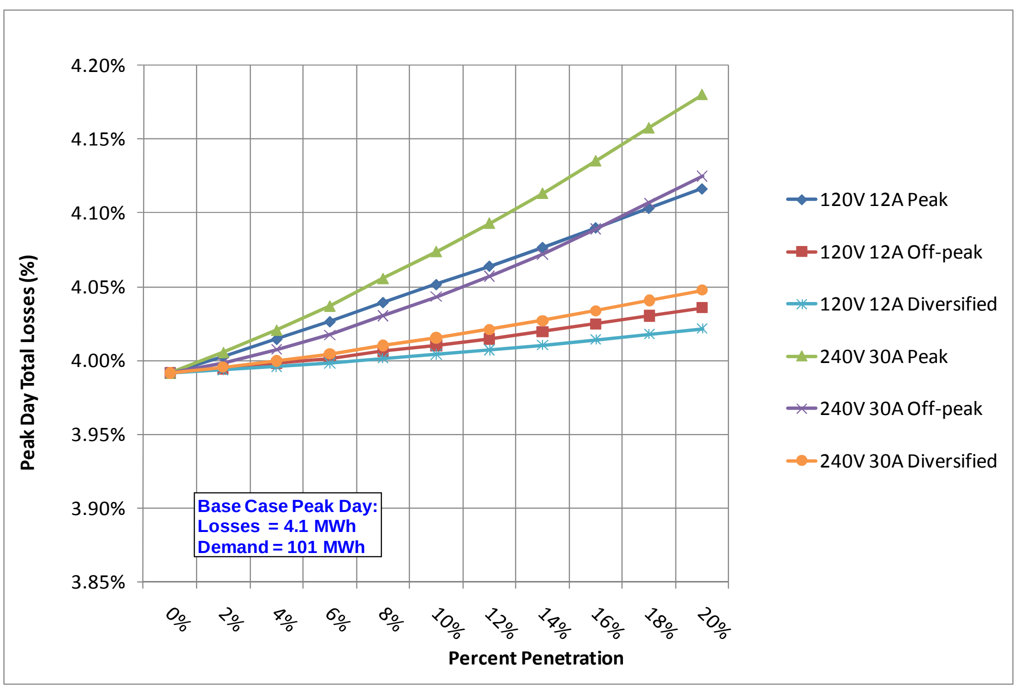

Figure 5-26
System Deterministic Case Total Peak Day Losses

Duke Market Assessment and Cluster Study

As part of EPRI distribution impact analysis, Duke performed a detailed market assessment to model PHEV adoption, preference of PHEV types, and propensity to charge at night. Duke's market assessment study examines how the adoption of electric vehicles can often cluster within a neighborhood or on a particular street. The methods used in this study were successful in identifying electric vehicle market segments that occur in statistically significant geographical clusters. The results validate an a priori proposition that geographic clustering may occur when overall PHEV penetration is still low. Figure 5-27 – Figure 5-29 show the capacity load at risk for secondary transformers at individual summer peak and nameplate ratings with additional load from 5, 10, and 20 percent EV penetration.

Duke's analysis shows that there is likely to be minor short term risk or reward for electric utilities with respect to electric vehicle adoption, but also that significant long term value or risk exists, depending on how judiciously utilities manage pricing, charging and infrastructure. The margin of difference between profit and loss lies with the extent to which customer adoption is geographically clustered, whether customers demand faster charging times, and how utilities are able to insure optimal charging times are met, relative to existing system utility peak loads. Customer car purchases are likely to cluster geographically within neighborhoods. Customers appear to want fast charging and convenience, albeit within some price tolerance.

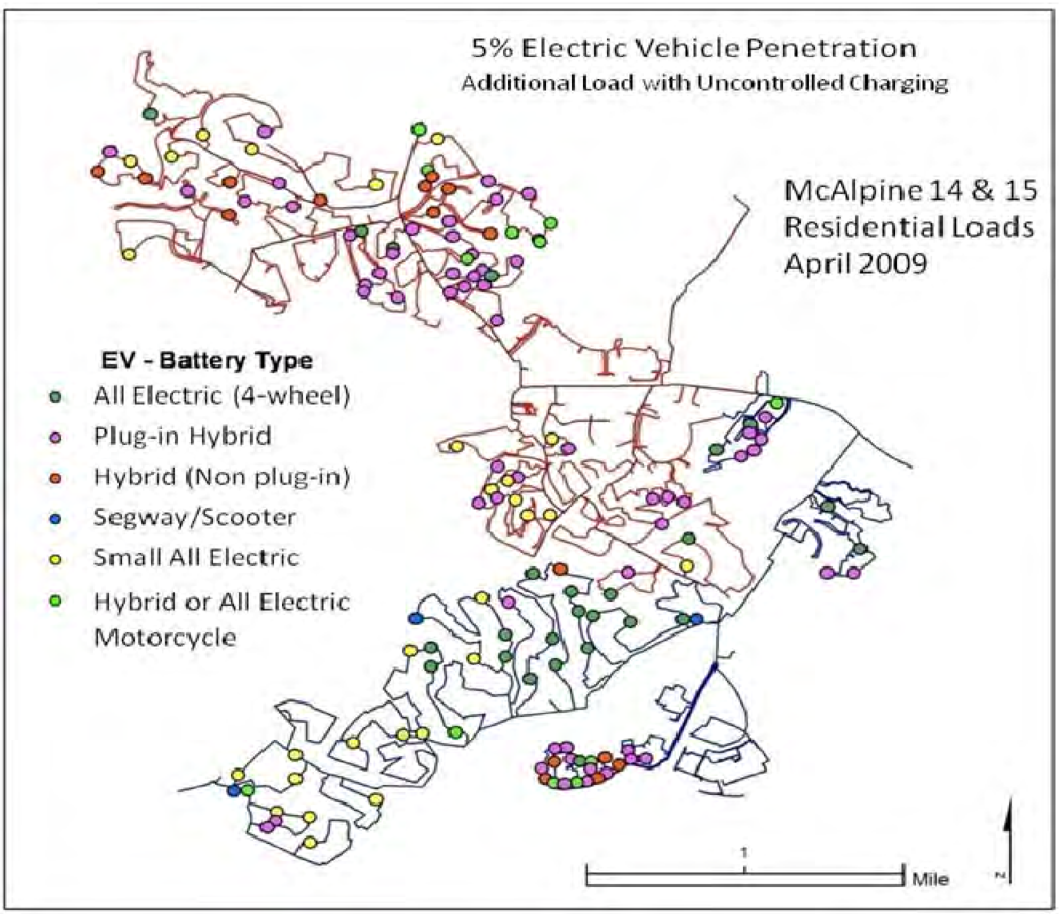

Figure 5-27
Display of most preferred EV on each secondary transformer for 5% EV Penetration

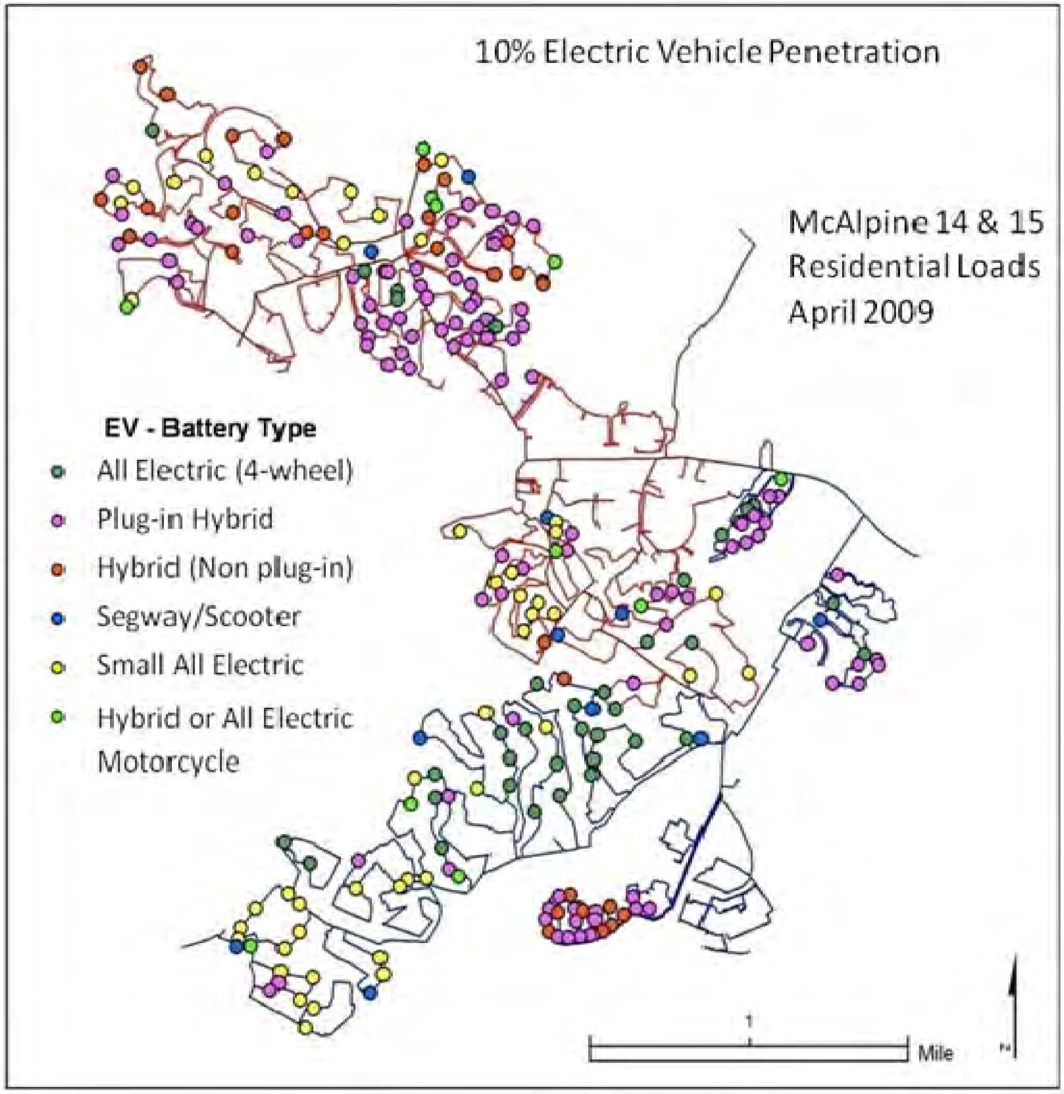

Figure 5-28
Display of most preferred EV on each secondary transformer for 10% EV Penetration

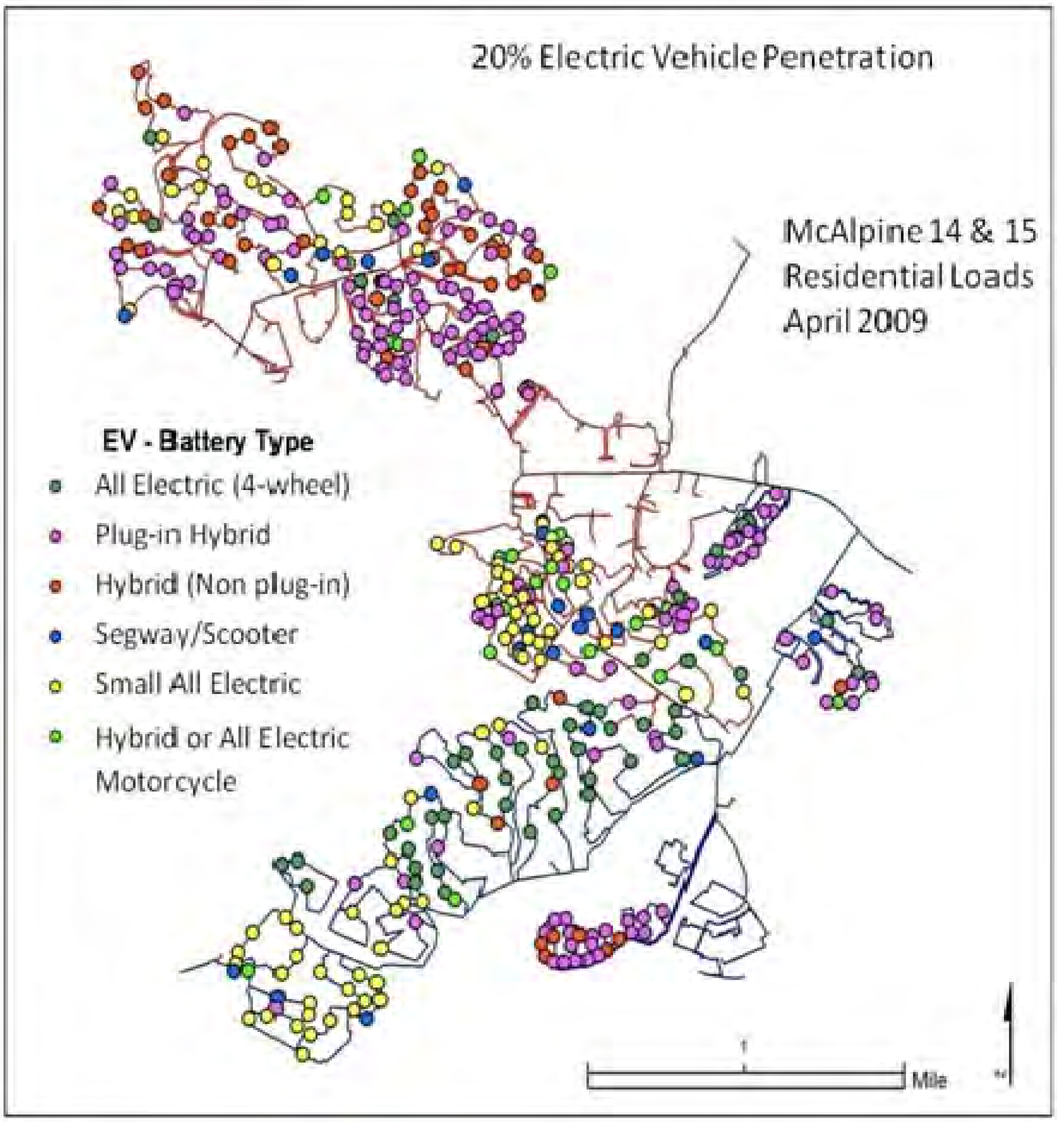

Figure 5-29
Display of most preferred EV on each secondary transformer for 20% EV Penetration

Conclusions

While the residential charging standard can reach power levels of 19.2 kW (80 amps at 240 volts), most vehicles are expected to charge at power levels below 7 kW. PHEVs can very comfortably recharge overnight at Level 1 (120V, 1.2 kW) or at the lower rates for Level 2 (240V, 3.3 kW). The specific impacts for any feeder will depend on the design and loading practices for various components of the feeder and assumed PEV characteristics for the area.

Deterministic and stochastic analyses of the potential load impacts on an actual distribution circuits are being conducted as part of a multi-utility project. The results to date, however, generally show the following:

- The extent of system impacts depends upon the PEV penetration and charge behaviors of PEV adopters
- Due to diversity, the expected aggregate addition to system peak loads is 700-1000 Watt per PEV in a given utility territory. Based on typically daily driving statistics, the average energy delivered to a vehicle during a charge is 5-8 kWh for a midsize sedan.

- Recognizing that all distribution circuits will not realize the same level of PEV adoption, the extent of system impacts depends upon the PEV penetration and charge behaviors of PEV adopters
- The short-term impacts for most utilities studies should be minimal and localized. There is a possibility, however, of isolated impacts on some distribution transformers and secondary drops, particularly in neighborhoods with older distribution systems including underground systems.
- By system design, per-capita load growth (PEV or otherwise) will first impact devices closest to the customer
- Components closer to the customer are the most likely to be impacted as they do not benefit as greatly from PEV load diversity
- Low capacity per customer ratios combined with low PEV load diversity (assets closer to the customer) are the most likely to be impacted as they do not benefit as greatly from PEV load diversity
- The remaining capacity per customer can be used as a metric for evaluating possible risk of impact due to customer adoption of PEVs
- The assets near the load are most susceptible to PEV clusters as the potential benefit of spatial diversity decreases. Older distribution systems (including underground systems), initially designed for much lower per-customer load than its current operation, it is likely that the PEV impacts are more severe and impactful than to a relatively newer infrastructure.
- Based on system configuration and customer adoption, PEV clustering will occur randomly throughout the system. While PEV clustering may indicate an increased risk higher than average loading levels, PEV clustering alone does not signify the likelihood of negative impact occurrence as the other PEV load characteristics must also be taken into account
- Transformers characterized by low capacity per customer ratios are the most likely to be impacted by PEV adoption. Furthermore, transformers lower than 25 kVA nameplates are expected to be the most susceptible to becoming overloaded as these transformers typically have lower amounts of existing capacity which can be quickly consumed by one or more PEV.
- Likelihood of a given system component becoming overloaded is a function of the remaining capacity on the element and the number of customers served from the element that are potential charging locations for PEVs. The increased loading on the substation transformer tends to be tempered by the diversity in charging times for the many PEVs that are served across the entire feeder. Conversely, a single service transformer serving 5-10 customers may become overloaded with 1 or 2 higher charge current PEVs.
- Stochastic results show that the temporal and spatial diversity of PEVs charging on the system mitigates mass overloads of any particular asset class for penetration levels in the 2-8% range.
- Controlled charging can defer projected impacts due to load growth to later years, but care must be taken to ensure that the control strategy does not create secondary system peaks.

EPRI believes that potential stresses on power delivery systems can be mitigated through asset management, system design practices, controlled charging of PEV, or some combination of the three. But again, given the likely variability in customers' PEV choices, car types, varied charging patterns, varied charging speed preferences, and variable participation in utility-centric TOU charging options, we believe that the utility will not be able to manage this risk in an ex post fashion. In many cases, the utility will likely not be notified or aware of an PEV addition, or a unique charging pattern. As such, a proactive risk mitigation strategy is recommended to remove localized risk to the distribution system. Controlled charging can significantly reduce PEV loading impacts on the distribution system, but is not likely to be universally adopted. Tariffs and rates which encourage nighttime charging (e.g., load management, valley-filling, etc.) can also help to avoid or postpone upgrades. All of these factors can be taken into account in the analysis of potential risk as a function of distribution system conditions and geographic factors.

Section 6: Electricity Pricing for Plug-In Vehicles

Cost of Electricity as a Transportation Fuel

Electricity is one of the least expensive transportation fuels. Figure 6-1 shows the historical relationship of the relative transportation fuel costs of electricity and gasoline. The comparison is based upon historical retail gasoline prices in the U.S. and average residential electricity rates. In addition to much higher price volatility of the last approximately 35 years, at typical U.S. gasoline and electricity costs; gasoline is three to four times the cost of electricity as a transportation fuel.

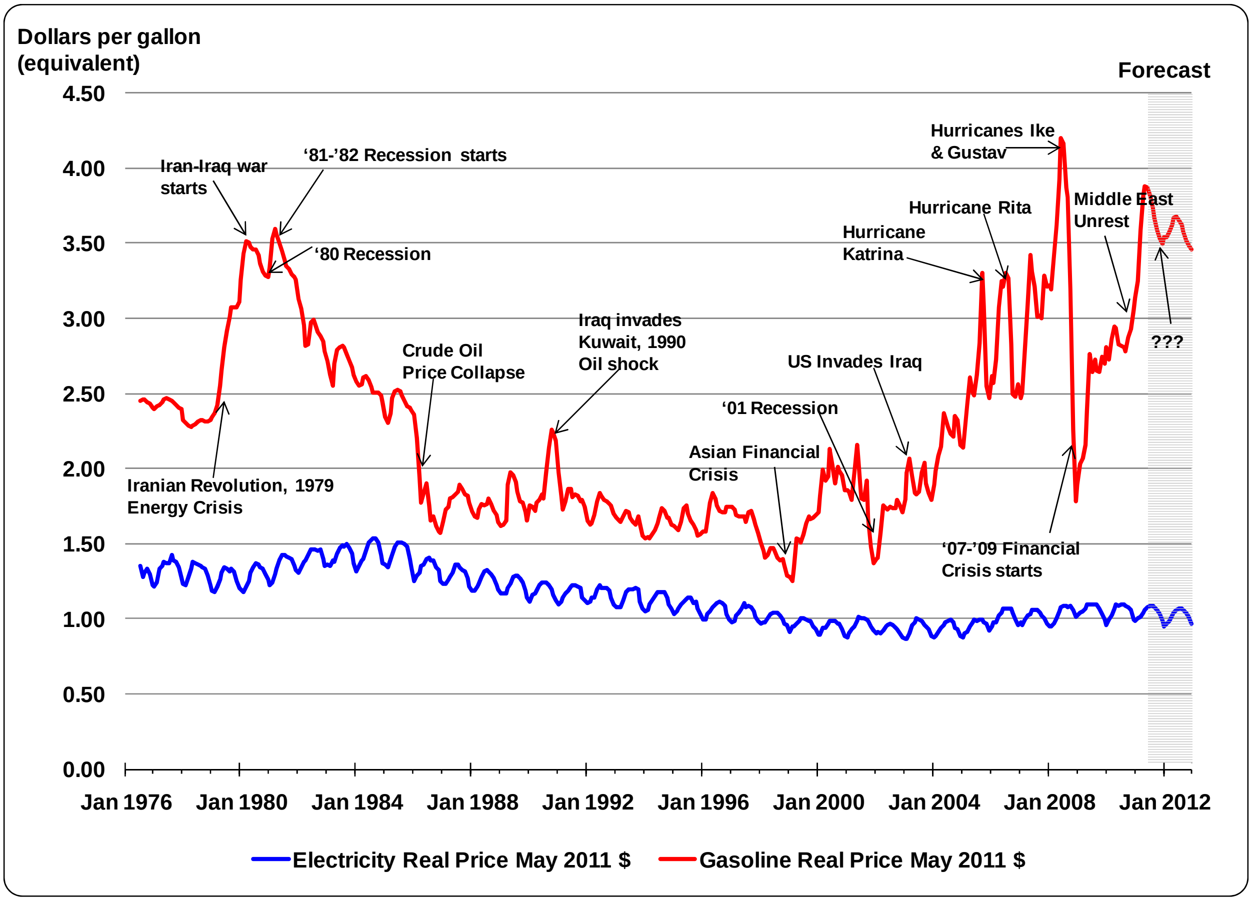

Figure 6-1

Comparison of gasoline equivalent fuel costs between electricity and gasoline. Based on plug-in electric vehicle with an efficiency of 3.4 miles/kWh (similar to Nissan Leaf) compared with an internal combustion engine vehicle with a 30 mpg fuel economy rating. Graph courtesy of Edison Electric Institute[22]

[22] Energy Information Administration, Short-Term Energy Outlook, May 2011. Data compiled, converted, and presented by the Edison Electric Institute

Time-of-Use Electricity Pricing

Most electric transportation stakeholders generally assume that utilities will implement time-of-use (TOU) electricity pricing to incentivize PEV owners to charge predominantly during the nighttime hours. As described earlier, off-peak charging can both reduce or eliminate PEV contribution to peak system demand (reducing potential need for future powerplants) and reduce the impact to the distribution system.

TOU pricing can reduce peak electricity demand. In a recent 2008 pilot study, Salt River Project used TOU pricing in tandem with smart metering to reduce residential whole house on-peak usage by up to 25%.[23] With respect to PEVs, there are three significant challenges with the use of TOU pricing to encourage off-peak charging:

1. Electricity is a relatively inexpensive transportation fuel and even high on-peak rates may not be sufficient economic incentive to delay charging.
2. Owners of battery electric vehicles may be reluctant to delay charging and may prefer to keep the battery state-of-charge as high as possible.
3. Owners of plug-in hybrid electric vehicles that choose to delay charging may end up consuming more gasoline, possibly increasing their energy costs.

Despite these challenges, time-of-use pricing is likely to be a valuable tool. The rate structure has to be designed carefully in order to achieve the desired effect since consumers will perceive not only a price differential between two different charge times, but also a price difference between electricity and gasoline propulsion. Since gasoline is relatively more expensive and has a higher price volatility than electricity it will be difficult to design a rate that is both desirable enough that users will forgo a flat rate at reasonable prices and has a high enough price differential that users will be sufficiently incentivized to charge off peak.

It will be important to account for the somewhat different requirements of BEV and PHEV owners. BEV users may periodically choose to charge immediately depending on their immediate driving needs. This creates a complex response to time-of-use rates which is difficult to analyze, especially with the limited data available today.

The situation for PHEV drivers is somewhat different. PHEV generally have less electric driving range than BEVs—typically between ten and forty miles—but can continue driving on gasoline indefinitely after the stored electricity is depleted by refilling the fuel tank. BEV drivers will avoid using the full electric range of their vehicles in order to avoid running out of stored electricity, while PHEV drivers will be essentially indifferent to 'running out' of electricity since they will not be stranded waiting on a recharge; they will simply switch over to gasoline. This feature has the advantage of enabling the use of grid-powered vehicles by a wider variety of drivers and allowing the use of smaller, more cost-effective batteries. However, this feature also creates a potential problem for the design of time-of-use electricity rates. PHEV drivers do not have to charge in order to get home, but they are also likely to value the cost of daytime charging relative to the cost of using gasoline. Since gasoline is significantly more expensive on a per-mile basis than electricity, the user is likely to have a relatively high price threshold for daytime electricity. If a flat rate comparable to current prices is available, PHEV drivers will be much more likely to choose the flat rate, even if they have to forgo the benefit of a low nighttime rate.

Customer Response to Electricity Pricing Options

Assuming that electricity pricing options for PEVs can be designed with an economic benefit to the owner, the initial customer response to these programs appears to be favorable. Southern California Edison customers were surveyed for their response to three different pricing options for electric vehicle charging:

1. "Anytime Plan" – 24/7 charging at a flat, fixed rate. Total savings (compared to a gasoline vehicle) of $650 per year.
2. "Night-time Discount" – A discounted rate for charging from 9pm to 8am. Total savings of $1,000 per year.
3. "Flat-rate/Night-time Only" – A flat monthly fee for charging only between 9pm and 8am. Total savings of $1,100 per year.

[23] 'Effects of the EZ-3 (E-20) Time-of-Use Plan on Summer Energy Usage of Residential Customers. Report under preparation. Salt River Project. 2010.

Additionally, each of these pricing plans had a 'demand response style' option for the utility to interrupt charging for one hour for an addition $100 per year saving to the customer.

In Figure 6-2, most surveyed customers expressed a preference for a night-time charging plan and the accompanying additional savings. A smaller, but still significant portion preferred the more restrictive "Flat-rate/Night-time Only" plan even though its economic advantage over the "Night-time Discount" plan was small.

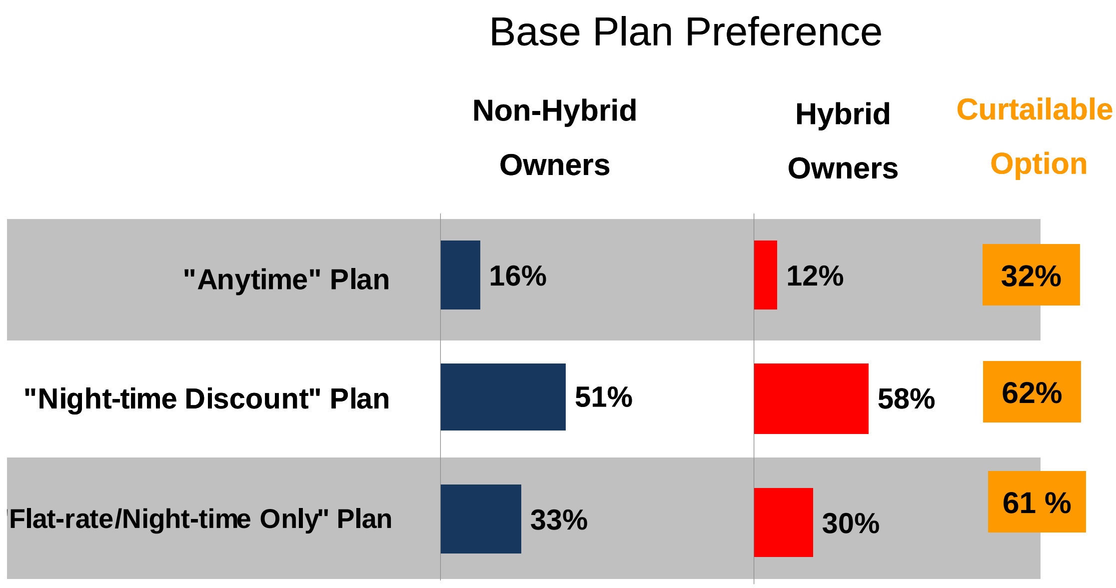

Figure 6-2
SCE Customer preference for different charging plans[24]

Section 7: Potential Roles for the Electric Utility

This chapter describes a number of potential roles that an electric utility can incorporate into an electric transportation program to support and to enhance the adoption of plug-in hybrid and electric vehicles in its service territory. These recommendations were designed to specifically consider the unique attributes of an electric utility as an electric transportation stakeholder—electrical system and equipment operational and technical expertise, extensive network of capital equipment and personnel throughout its territory, and pre-existing relationship with nearly all residents, business, municipalities, and other regional stakeholders.

The electrification of transportation can result in many positive environmental and economic impacts that would result in both societal and ratepayer benefits. However, there are numerous uncertainties associated with the introduction of an entirely new transportation energy source, including, vehicle availability, customer adoption, and infrastructure development. Utility engagement in appropriate areas can help to reduce uncertainty, positively impacting the adoption of electric vehicles.

No aspect of this report, including the potential roles described in this chapter, implies regulatory approval or economic feasibility. Regulatory permissibility, financial impact, strategic importance, and overall feasibility and appropriateness of each recommendation must be specifically determined in each case.

Consumer Education and Outreach

Utilities can play a specific and valuable role in educating their customers about adopting electric vehicles. Active outreach to its customers can increase the rate of vehicle adoption in its service territory, reduce customer confusion, and improve the utility's customer satisfaction. Utility's have a prior history of informing and educating their customers on new consumer products—energy efficient appliances, for example. Customer education can also serve as a strategy to manage the grid impacts of PEVs, primarily by educating PEV adopters on grid-friendly charging behaviors.

Most utilities consider electric transportation to be a customer-focused program. The left-hand side of Figure 7-1 shows 2009 survey responses from Southern California Edison customers regarding their expectations of information that would be provided by their electric company. These expectations run the gamut from information on charging infrastructure, to the actual plug-in vehicles themselves, including early adopter experiences and their environmental benefits.

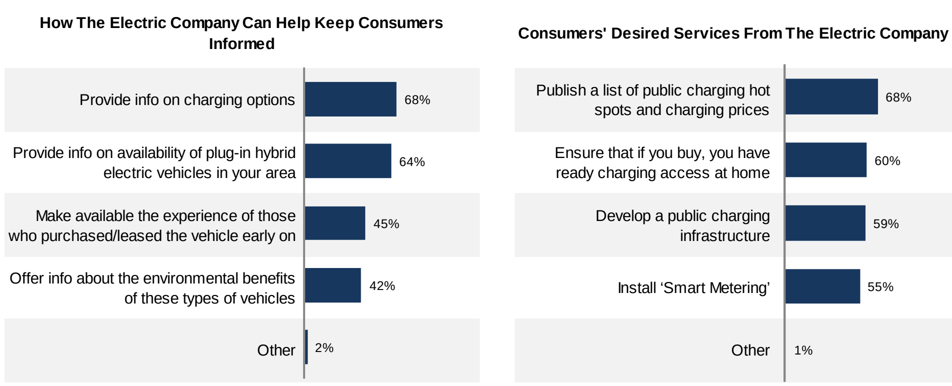

Figure 7-1
Consumer information and service expectations from their electric company[24].

[24] *Characterizing Consumers' Interest in and Infrastructure Expectations for Electric Vehicles: Research Design and Survey Results.* EPRI, Palo Alto, CA and Southern California Edison, Rosemead, CA: 2010. 1021285

Surveys have also shown that while there is widespread interest in plug-in vehicles, the overall level of understanding of the technology by the general public is low. [24,25] An automobile purchase is a major financial commitment and prospective PEV adopters are likely to have many questions about both vehicles and charging infrastructure. Utilities are an important source of trusted, accurate, unbiased information to the consumer. The following list contains some of the general categories of vehicle and charging information sought after by PEV intenders:

- Explanation of the differences between battery electric vehicles and plug-in hybrid electric vehicles
- Specific, up-to-date model information on all PEVs, including cost, real-world range, charge time, expected battery reliability, operating costs, etc.
- Safety of PEVs, primarily electrical and crash
- Product information on EVSEs
- Information and guidance on installing a home charging system, including permitting and inspection, capacity of existing electric panel and service, estimated costs
- Information and guidance on installing EVSEs at multi-unit dwellings and commercial businesses
- List of qualified electricians that install EVSEs
- Utility rate or other incentive programs for PEVs
- Availability and location of public access charging locations

Information Delivery

A utility should develop its overall communication strategy to support its objectives in electric transportation. In general, most utilities formulate either a soft or strong leadership position for electric transportation. Soft leadership is generally characterized by a reactive approach and strong leadership by a proactive approach and moderately increased investment in activities or programs designed to enhance electric vehicle adoption. In many cases, both approaches require similar informational needs. A third approach, a passive supporter of electric transportation, is generally the default approach of utilities that have not completed the formulation of an ET strategy, but to date has not been formally adopted by any utility.

A utility has a number of channels for communicating with its customers and delivering information on PEVs:

- Company website
- Call Center
- Customer Service Centers
- Bill Mailings
- Press releases, other local media opportunities
- Conferences, fairs, shows, expositions, and other public events

Each communication channel or opportunity should be utilized in specific ways to support the overall communications strategy. At a minimum, utilities can expect customers to contact call centers and possibly in-person customer service centers with specific questions about different models of PEVs, installation of infrastructure, availability of public charging, etc. The utility may elect to leverage different public events to announce PEV programs, highlight its leadership in technology, and perform more specific or planned forms of outreach.

Outreach and Education

Utility outreach and education objectives can result in a material impact on the utility system. Informed customers will make informed decisions, whether it is purchasing a PHEV vs. a BEV, installing a charger with a certain power level, or adopting grid-friendly charging behaviors.

Figure 7-2, below, shows the expectations of SCE customers regarding charging time for their vehicles. These survey respondents have been educated on the basic tenets of PEV charging. A majority of both hybrid and non-hybrid vehicle owners generally indicate that 'overnight' charging of their vehicles will meet their expectations. These expectations can generally be met by either Level 1 charging of a PHEV at 1.4 kW or Level 2 charging at the lowest level—typically 3.3 kW—for a BEV.

PEV buyers will be offered a wide variety of choices for EVSE installation through a number of possible channels, including auto dealerships, aftermarket

[25] Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options, EPRI, Palo Alto, CA: 2001. 1000349.

installers and electricians, appliance stores, and others. The power level of these residential EVSEs will range from 1.4 kW (120 VAC, 15 amp circuit) to 19.2 kW (240 VAC, 100 amp circuit). As long as the customer's expectation of charging time can be met, the economic interests of the PEV purchaser and the utility and its ratepayers are typically optimized by installing a lower power level charger. As described in Chapter 3, this will generally reduce the local impact to the distribution transformer. The customer will almost certainly experience lower equipment and electrical installation costs while minimizing the probability of requiring a costly panel upgrade. In many cases, this type of decision making can be achieved by the customer understanding the charging requirements of the vehicle they have purchased relative to their driving habits. It is likely that similar scenarios are possible for charging behavior, vehicle purchases, and other key decisions.

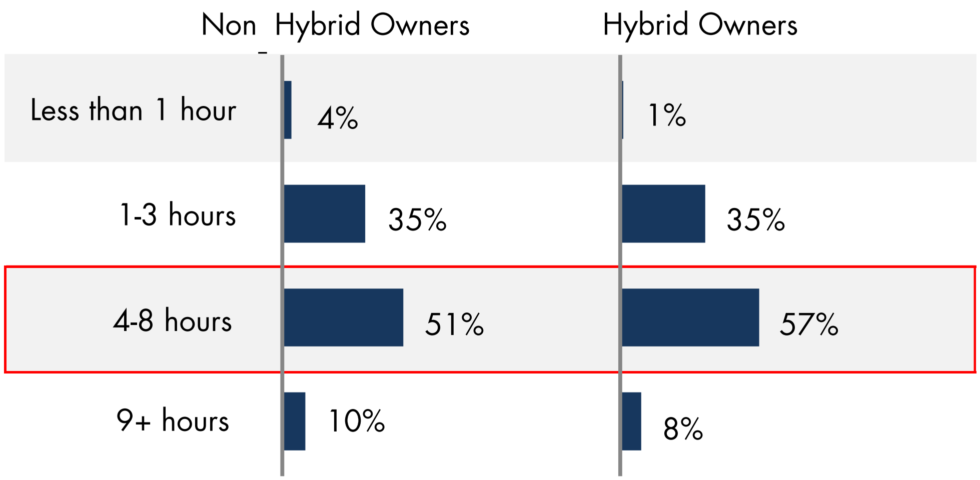

Figure 7-2
Expected time to charge a PHEV, non-hybrid and hybrid owners.

Customer Expectations

The right-hand side of Figure 7-1, above, shows additional survey results of SCE customers regarding their expectations of services that their utility might provide. These results indicate a clear customer expectation—in Southern California—for the utility to actively facilitate both public and residential charging infrastructure access.

Critical Infrastructure and Services

The concept of critical infrastructure and services involves a utility actively guaranteeing a minimum 'safety net' of vehicle and infrastructure support services within its service territory. A critical infrastructure and services program would consist of one or more of the following features:

- Critical charging infrastructure – establishment of secure and reliable charging locations throughout the utility service territory where privately owned charging facilities are not available.
- Customer assistance – operation of a 24-hour help line (possibly as part of the utility call center) to assist electric vehicle owners in the emergency location of charging locations. In situations where a BEV is stranded without access to charging facilities, the utility may also offer a specific towing service
- Emergency services – the growth of public charging will likely create an unprecedented exposure of the public to high-voltage equipment that is relatively easily damaged and may at times present a safety risk. Utility maintenance crews can serve as one option to de-energize and secure damaged EVSE

equipment when normal service personnel are not available (nighttime, remote areas, etc)

Critical Charge Infrastructure

The role of critical charge infrastructure is to create and maintain a safe, secure, and reliable network of charging stations to ensure the safe operation of battery electric vehicles between metropolitan areas and in rural areas.

Greater than half of the announced plug-in vehicle models over the next three years are battery electric vehicles. BEVs are particularly well-suited to most commute driving and short urban trips and most infrastructure planning recommends a near-term focus on installing both sufficient public infrastructure in urban areas for convenience charging and adequate infrastructure along prominent highway corridors. These proposals are based on the theory that drivers will adopt electric vehicles and operate them in areas where there is sufficient charging infrastructure to alleviate concerns about vehicle range and to provide numerous opportunities for convenience charging to maintain a relatively high battery state-of-charge.

Tokyo Electric Power Co. (TEPCO) conducted an electric vehicle fleet demonstration in Tokyo that clearly illustrated these concepts.[26] At the beginning of the demonstration TEPCO employees only had access to a charger at the company headquarters. Consequently, trips in the company's demonstration BEVs were short (207 km/month total) and the vehicles always returned with a battery SOC greater than 50%. After locating a single DC charger at the midpoint of their driving routes, monthly mileage was observed to have increased to 1472 km/month and the vehicles nearly always returned with a battery SOC less than 50%. TEPCO also observed that the second charger was not used very often—its mere presence was enough to provide the drivers confidence that they could complete their trips.

Past experience, however, has also shown that electric vehicles will not be limited to defined commutes and urban driving. Electric vehicles have been driven the entire length of the United States. Electric vehicle owners in California regularly drove from the San Francisco Bay Area to Los Angeles or over the Sierra Nevada mountains to South Lake Tahoe, among a number of other locations.[27] It is a virtual certainty that electric vehicle owners will drive long distances and unpredictable routes that take them outside of urban areas and the most popular highway corridors. They may often be exposed to inclement weather and varying driving conditions that will significantly reduce the range of their vehicles. Nissan recently stated that the nominal 100 mile range of the LEAF electric vehicle could range from 62 – 138 miles depending on speed, level of congestion, and ambient temperature. [28]

Much of the U.S., due to its size, geography, and climate, is challenging for battery electric vehicles. To use Oregon as an example, the Oregon State Highway System is comprised of approximately 8,038 miles of roads, 730 miles of which are interstate highway.[29] The total road system for the state, including federal, state, and local roads, is certified at 75,611 miles. Like most large states, Oregon has both high density regions (Multnomah County, population density of 1518 people per square mile) and extremely low density regions (Harney County, population density of 0.75 people per square mile).[30]

Oregon features a wide range of weather and ambient temperatures, which can reduce the range of BEVs while also posing a safety risk to drivers who may run out of charge in these conditions.[31] Oregon is well known for its expansive mountain ranges that contribute to the state's reputation for natural beauty—however climbing a 6% grade can more than triple the per mile electricity consumption of a plug-in vehicle. These issues are compounded by the fact that significant areas in Oregon lack digital cellular coverage in the event that a BEV driver becomes stranded.[32,33]

[26] Anegawa, T., 'Desirable characteristics of a public quick charger,' Plug-In 2009, Long Beach, CA. 2009

[27] Ed Huestis, personal communication, 2001.

[28] Tavares, C., 'Nissan LEAF: Innovation for All,' Plug-In 2010, San Jose, CA. 2010.

[29] 2008 Oregon Mileage Report, Oregon Department of Transportation. 2008.

[30] National Association of Counties. http://www.naco.org. Retrieved April 26, 2007.

[31] http://www.wrcc.dri.edu/narratives/OREGON.htm

[32] http://www.wireless.att.com/coverageviewer

[33] http://www.verizonwireless.com/b2c/CoverageLocatorController

Preliminary Estimates of the Scope of Critical Infrastructure

It is important to estimate or consider the quantity of equipment required to construct an adequate regional critical infrastructure. At first, the concept of a statewide infrastructure may appear daunting. The following estimates serve as some very simple scenarios of adequate statewide critical infrastructure (in each case assumed to consist of a single Level 2 EVSE at approximate spacing of 10 miles). Continuing with Oregon as an example of regional infrastructure:

1. Locate one station every 10 miles of the Oregon State Highway System (8,038 miles) – Requires 804 installed EVSEs.
2. Install one station on a 10 mile grid spacing across the length and width of Oregon (360 miles long by 261 miles wide) – Requires approximately 999 EVSEs (37 by 27 grid).
3. Install one station for every fifty square miles of Oregon land area (96,003 square miles) – Requires 1,920 EVSEs.

The use of ten-mile spacing is somewhat arbitrary; however at this spacing it is likely that a BEV driver can reach at least one or two of the stations under most conditions, even toward the end of the vehicle's charge.

Based on the range of EVSE equipment and installation costs from Chapter 3 ($4,500 to $8,000 for public infrastructure) would result in an estimated cost for these critical infrastructure scenarios ranging from $3.6 million to $15.4 million.

Critical infrastructure, by definition, is positioned to enable coverage of a defined region. Much of this infrastructure will likely see infrequent use and low generation of revenue. Therefore, it is likely that a standard for-profit ownership model is not compatible with the development and maintenance of a regional critical charge infrastructure network.

Conventional Charging Infrastructure

The residential, commercial, and public charging infrastructure that are located in closest proximity to the places where vehicles are driven and parked will support the majority of charging requirements of a regional plug-in vehicle fleet. Electric utilities should carefully consider their role (if any) in development and maintenance of this customer-side electrical equipment.

Residential Infrastructure

Residential infrastructure is the workhorse of any electric vehicle fleet. 95% of customer-owned vehicles end each day parked at the owner's residence. The average vehicle spends 80% of its total life parked at home. There a number of challenges to seamlessly establishing residential infrastructure—however it is certain the plug-in vehicles cannot be commercially successful if consumer cannot conveniently and economically prepare their residences for daily charging of the plug-in vehicle of their choice.

Utility roles in residential infrastructure for consideration include:

1. Customer education – communication channels frequently used between the utility and its customers can be utilized to help customer understand PEV characteristics and charging requirements, EVSE sizing and installation, identification of qualified electrical contractors, understanding of permitting and inspection requirements for local jurisdictions, and estimating typical installation costs.
2. Rate selection – where a utility offers a TOU or EV-specific rate, assist the customer in understanding the energy requirements of their new PEV and in deciding on the most appropriate rate option.
3. Home inspection – the utility provides or facilitates a free or discounted service to a customer for an electrical inspection and estimate of EVSE installation cost. This service enables a utility to locate potential customers and understand local impacts to the distribution system.
4. Aggregated EVSE installation – the historical residential EVSE costs are high and exceed current understanding of customer willingness to pay.24 Existing data from Progress Energy and Southern Company (Chapter 5) indicates that a utility, either acting directly as an aggregator or through a separate electrical contractor, can conduct multiple installations at significantly reduced costs—possibly greater than a 50% reduction over historical costs.
5. Facilitation of EVSE installation at rental and multi-unit dwellings (condominiums, apartments, and rental houses) – Many areas, particularly in cities that are normally associated with the 'early adoption' of PEVs, have a high percentage of rental

units—the PEV buyer may not own the property on which they park their vehicle. The utility can serve an outreach role by actively educating and encouraging property owners to consider tenant requests for EVSE infrastructure while developing best practices and guidelines to address the challenges of large, multi-unit housing complexes.

Commercial Infrastructure

Commercial infrastructure includes all private infrastructure to support a company's fleet or employee vehicles (i.e., generally not available to the public). Charging infrastructure is a significant component of the cost of fleet electrification and must be clearly understood by a company considering adding charging equipment for its fleet or employees. Commercial infrastructure has positive implications for a utility—workplace charging of employee vehicles increases their utilization of electricity (further reducing gasoline consumption) by providing a second opportunity to charge per day while fleet charging is generally very predictable can relatively easily be moved off-peak. Utility roles for commercial infrastructure can include:

1. Customer education – utilizing customer account representatives to educate potential commercial adopters and encouraging the consideration of PEV fleet adoption and provision of workplace charging facilities.
2. Fleet experience – the utility can share its own experiences in fleet electrification—particularly vehicle selection, operational logistics, and total cost of ownership—with potential commercial adopters.
3. Provide or facilitate building or facility electrical audits to promote the understanding of infrastructure costs – this can include combined energy efficiency/PEV infrastructure audits and analyses to reduce both peak load and service upgrade costs, planning and layout of charging infrastructure to minimize installation costs.

The utility can serve a very valuable and credible role in helping it commercial customers develop their own electrification plans. The utility's own experiences in fleet electrification and in providing employee charging facilities is crucial to establishing the credibility and providing sound data on the costs and benefits of PEV adoption to commercial customers.

Public Infrastructure

Public infrastructure—which includes all publicly accessible EVSE whether located on public or private property—currently receives the most attention of the three infrastructure categories. The utility is likely to be one of many stakeholders advocating for, planning, and implementing public infrastructure. As described earlier, the costs of public infrastructure are likely to be high relative to the expected generated revenue—utilities may own some token infrastructure at service centers or other public locations (possibly also considered to be part of a critical infrastructure strategy) to demonstrate early leadership, facilitate the growth of a larger public infrastructure, or to collect data—however utility ownership of a larger regional network of public infrastructure is not anticipated to be economically feasible if done outside the rate base.

Potential utility roles for public infrastructure can include:

1. For privately owned public infrastructure (retail locations, etc.) the utility can serve many of the same roles as with commercial workplace or employee infrastructure.
2. For parking facility owners considering a significant EVSE installation, the utility can serve many of the same roles as with commercial fleet infrastructure.
3. The utility should serve as an active stakeholder voice in any public infrastructure planning process. It is in the utility's interest that public infrastructure be well-planned and perceived as a responsible use of public funds. The utility's familiarity with the area and experience with large infrastructure projects can serve as an important asset to the planning process.

Expedited EV Infrastructure Service Requests

In the near term, service requests (upgrades, second meters, etc) related to EV infrastructure will have a very high level of visibility and a likely expectation of response time that is significantly lower than currently provided. The utility should carefully consider the likely nature and frequency of these requests and where possible, streamline internal processes to attempt to meet customer needs.

Understand and Mitigate System Impacts

Utilities are in the early stages of understanding the system impacts and likely associated costs of PEV adoption in their service territories. This is absolutely and clearly the traditional responsibility of the electric utility. As described in Chapter 4, the early stages of PEV adoption are likely to create very specific and local impacts to the more modestly sized distribution transformers and other local components. There are a number of actions utilities can take to understand and prepare that will ultimately reduce impacts to cost and service, including:

1. Component-level distribution impacts analysis – the utility should understand how its current distribution system and most common circuit designs are likely impacted by PEV adoption—this can vary widely from region-to-region and utility-to-utility.
2. High-level distribution impacts analysis – this analysis consist of a general inventory of utility circuit loading over the entire system to determine areas of possible early impact. When combined with component-level analysis the utility can develop an effective understanding of overall PEV grid impacts.
3. Understand clustering – distribution impacts are exacerbated by the clustering of PEV adopters in given neighborhoods. Utilities can use existing customer demographic information to understand which areas may see clustering.
4. Work with automotive companies on early notification – directly notifying the utility of a customers impending PEV purchase (which requires the customer's permission and is facilitated by the automotive dealership) has been identified as possibly the single most effective method to understand and minimize distribution impacts—the utility will be aware of the location of the PEV and can either proactively or reactively upgrade the transformer if necessary. This also enables the utility to conductive proactive customer outreach on EVSE sizing and installation and rate selection.

Fleet Adoption of Electric Vehicles

The utility must set the example for the fleets and businesses in its service territory. In many cases, commercial adoption of PEVs is likely to be much slower than consumer adoption due to traditional fleet practices and a lack of understanding of the technology. The utility can achieve a number of benefits from fleet electrification:

1. Understand the real-world performance and requirements of PEVs – particularly under some of the demanding fleet applications common to utilities.
2. Understand the operator viewpoint and requirements for migrating to PEVs
3. Compliance with EPAct and other regulatory requirements.
4. Reduce fleet carbon footprint, criteria emissions, and petroleum consumption
5. Understand the costs associated with fleet infrastructure installation
6. Collect data on vehicle performance, charging, and local grid impacts
7. Understand the total cost of ownership for both near-term and long-term PEV technologies

Research, Development, and Demonstration

Planning for the adoption of plug-in vehicles and the installation of their supporting infrastructure should be a highly data-driven process. Unfortunately, there is a general lack of real-world data to support these efforts, particularly the near-term planning and regulatory activities that might govern the initial rollout of PEVs. Technology will also play a key role in the long-term success of electric transportation—especially toward achieving an effective integration of plug-in vehicles with the electric system.

There are a number of utility research, development, and demonstration efforts in electric transportation. The electric utility, as the fuel provider for plug-in vehicles, must play a critical role in understanding their requirements, collaborating with the vehicle manufacturers, and developing both existing and future technologies to enable a seamless integration of PEVs to the electric system.

Plug-In Vehicle and Infrastructure Research and Development

Important infrastructure research activities include the development of charging standards, testing and demonstration of vehicle infrastructure and charge station technologies and products, testing and evaluation of prototype plug-in vehicles, and the evaluation of advanced battery systems for PEVs. A primary focus of this work is 'smart charging,' a suite of technologies to enable PEVs to communicate with smart metering infrastructure and other aspects of the smart grid for the purposes of integrating PEV charging demands seamlessly to the grid with minimal system impact while completely serving customer demand.

General Motors – Utility – EPRI Collaborative

More than 50 utilities began collaborating directly with General Motors and EPRI in 2007, after GM announced the development of the Chevrolet Volt Extended Range Electric Vehicle. This collaboration is the most extensive example of utility industry collaboration with a major automaker and includes:

- GM-Utility collaboration on the commercial introduction of plug-in vehicles and the development of a seamless customer experience for both the vehicle adoption and infrastructure installation.
- The demonstration of roughly 155 Chevrolet Volts in a captive utility test fleets throughout the U.S. and Canada.
- The development of advanced vehicle-grid communication and charging technologies, including:
  - Telematics (GM OnStar) assisted smart charging
  - Direct vehicle communication to smart metering infrastructure to facilitate smart charging
  - Development of bi-directional battery technologies for both accepting and delivering stored battery energy to the grid
  - Demonstration and analysis of fast charging technologies
  - Use of PHEVs as a wind integration energy storage resource

Additional Research Topics for Consideration

Electric transportation—both PEV adoption and infrastructure implementation—should be a heavily data driven process and there are extensive needs for real-world operational data of both the vehicles and infrastructure. There are many research, development, demonstration, and analysis needs, including:

- Consumer research – preliminary survey work with Southern California Edison customers yielded many insights as to requirements and expectation of potential PEV buyers. Other utilities are also now performing similar consumer research in their service territories with their customers on both consumer expectations and PEV diffusion and market potential.
- Smart charging technology development and pilot programs – there are a number of pathways to managing vehicle charging, including onboard telematics, networked EVSEs, and direct vehicle communication to smart metering infrastructure. Utilities must understand how each of these pathways facilitates load management and enable customer programs for off-peak charging.
- Vehicle-to-Grid (V2G) – V2G is a concept where the PEV is bi-directional and can provide input power to the grid through the distribution system. V2G is the final stage in vehicle-grid integration that includes, sequentially:
  - PEV charging load is shifted to nighttime by simple techniques like electricity pricing, timers, and other customer devices
  - PEV charging load can actively be managed dynamically from a back-end server to perform system-level tasks like synchronizing with variable wind or solar generation.
  - A significant number of PEVs have bi-direction charging capability and can arbitrage energy at moderate rates (3-6 kW) on a more-or-less steady-state basis (Vehicle-to-Home or V2H).
  - A significant number of PEVs have bi-directional charging capability and can deliver ancillary services in a manner that is acceptable to system operators and compatible with the PEV's primary mission of providing transportation.

Program:

Electric Transportation

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