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Electric Vehicle Supply Equipment

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COMMENTS OR QUESTIONS

BRIAN SLOBODA
Senior Program Manager
brian.sloboda@nreca.coop

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NEW!

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Electric Vehicle Supply Equipment

By Bryan Jungers

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FAST FACTS

- Electric vehicle supply equipment (EVSE) is a term used to describe battery-charging equipment for plug-in electric vehicles (PEVs) that's not located on the vehicle. This name distinguishes offboard battery-charging hardware from its onboard counterpart.
- As of April 2013, nearly 6,000 public charging stations had been installed in the US—a 23 percent increase in just a six-month period.
- There are about 180,000 gasoline stations in operation in the US, which is 30 times as many facilities as there are public charging stations. However, considering that home and workplace charging are expanding and there are roughly 3,800 times as many gas-powered vehicles as there are PEVs driving on US roads, PEVs seem relatively well-supported.
- Although PEV charging represents a significant new load on the utility distribution grid at any recharge rate, relative impacts to grid operations will depend on how and where PEVs are recharged.
- Numerous assessments of PEV charging behavior suggest that the vast majority of charging events—on the order of 80 percent—take place either at home or at work and that most people prefer charging at home to other options. These tendencies significantly reduce the need for public charging infrastructure.
- Though a lack of interoperability between public charging stations and networks has been a hurdle, the industry is moving toward standardization that will benefit both individual PEV owners and the PEV market at large.
- Batteries and the electric grid have similar temperaments—they perform better for longer under mild power draw and temperature conditions. Hot summer days can be challenging both for the grid and for PEV batteries. Utilizing smart charging to avoid on-peak load during critical periods is in everyone's best interest.

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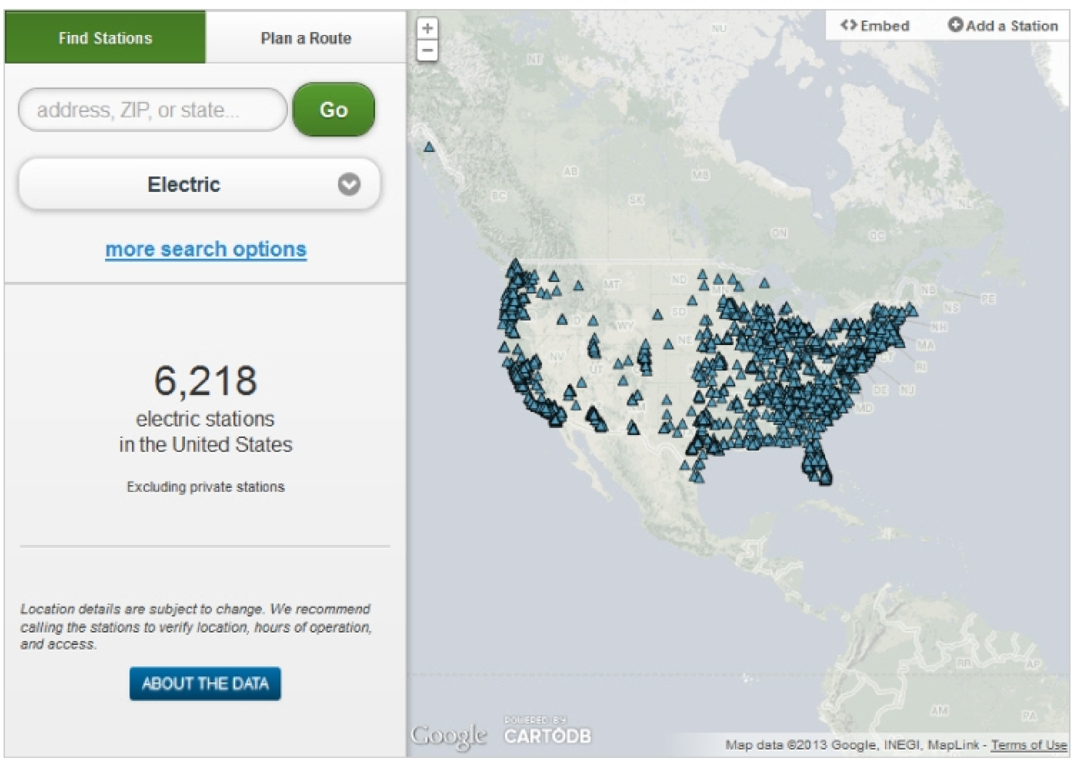
OVERVIEW

As the PEV market continues to grow, so does the need for access to compatible charging infrastructure. The form that infrastructure takes will determine how the use of electric vehicles (EVs) affects utility operations—PEVs are a significant new load, but their impact depends on how and where drivers choose to recharge. Although PEV charging comes in many types, the basic need remains the same regardless of the exact form it takes: By definition, PEVs require an external electricity source for their onboard battery charger to safely recharge their battery packs and displace gasoline use. In the case of plug-in hybrid electric vehicles (PHEVs), failure to recharge from an external source means the vehicle switches over to gasoline usage. For an all-electric vehicle, failure to plug in could leave the driver stranded. (For more details and differentiation of vehicle technologies, see our Resource Guide on Plug-In Electric Vehicles.)

As of spring 2013, roughly 100,000 PEVs were driving on US roads. According to the US Department of Energy's (DOE's) Alternative Fuels Data Center's (AFDC's) map of electric vehicle charging station locations (**Figure 1**), there have been more than 6,000 publicly accessible PEV charging stations installed across the country. That's one public station for every 17 vehicles. Compare that to having only one gasoline station for every 2,100+ gasoline vehicles in the US, and PEVs seem proportionally well-supported by the existing public charging networks. Considering also that there were only about 750 public charging stations in the US at the beginning of 2011, this infrastructure build-out occurred extremely quickly. Each charging station's power is supplied by and represents growth potential in both load and demand for its local utility. The degree to which charging stations, be they public or private, are necessary or sufficient to further the adoption of PEVs is uncertain and debatable, given that PEVs can easily be charged and operated without them.

FIGURE 1: Distribution of public charging stations in the US

The Alternative Fuels Data Center created an interactive map that shows all of the charging stations in the US. Early deployment of both plug-in electric vehicles (PEVs) and electric vehicle supply equipment (EVSE) was concentrated around major population centers, primarily along the west and east coasts of the US. On the West Coast, it's beginning to look like an all-electric trip from Baja to Bellingham is in the cards. East of the Mississippi River, EVSE coverage seems fairly dense and should provide a functional network that supports greater PEV adoption and more-electrified regional travel.



Source: US Department of Energy, Alternative Fuels Data Center

The primary differentiating factor between different PEV recharge methods and associated equipment is the rate at which the battery can be charged. Though this rate may be determined to some extent by the electrical current supplied by the offboard power source, the onboard battery charger serves as the ultimate limiting factor on the battery's maximum and minimum rates of charge. Though the terms are often confused, onboard equipment is referred to as the PEV "charger" while the offboard equipment that supplies electricity to the charger has been assigned the somewhat more convoluted name of "electric vehicle supply equipment." A PEV charging station is simply another name for EVSE, and it's used most commonly when referring to EVSE that's sited in public places. According to the National Electric Code (NEC)—which is administered by the National Fire Protection Association (NFPA)—the EVSE consists of all intermediary equipment placed between a facility's electrical wiring and the point where it connects to a PEV.

PEV charging represents a "boom or bust" opportunity for utilities. It is a significant new load on electricity distribution systems at any recharge rate, yet the degree to which it will affect grid operations depends on how and where drivers choose to charge their vehicles. Depending on the local energy-use characteristics for a given region, demand from a single PEV could be anywhere from about half the power drawn by a typical home to that of six or more homes, all added to the grid overnight. Charging from a standard 120-volt electric outlet represents the low end of the demand potential, versus the high-end requirements of PEVs charged using high-power EVSE. For more details on the potential energy and load impacts of PEVs, see the Performance section of our Plug-in Electric Vehicles Resource Guide.

Historically, charging rates have been denoted by numbered levels, each having defined voltage and current constraints. Along with the term EVSE, charging levels were codified in California by the state's Air Resources Board (CARB) in 1998 and were adopted into the NEC the following year. Charging levels were initially only designated for alternating-current (AC) electricity supply; more recently, direct-current (DC) electricity supply parameters have also been established for North America and added to SAE International's charge cord connector, PEV receptacle, and EVSE communications specifications, called SAE J1772. **Table 1** provides a comparison of PEV charging levels and connector types for AC and DC electricity supplies.

TABLE 1: PEV owners' options for recharging vehicle batteries

The slowest and most commonly available charging is AC Level 1, which is available from a standard 120-volt outlet and connected via a PEV's factory-supplied cord set. Accessing AC Level 2 requires an additional interface—car to EVSE to 240-volt outlet—to help ensure driver safety. DC Levels 1 and 2, as designated by SAE International, both require use of a high-voltage power supply and compatible EVSE to provide DC quick-charge capabilities.

	Voltage (V)	Maximum current (A)	Charge rate (mph)[a]	Analogous load
AC power level				
1	120	12 to 16	4 to 6	Hair dryer
2	240	15 to 80	12 to 64	Clothes dryer
DC power level				
1	200 to 500	80	53 to 133	5 houses (peak)
2	200 to 500	200	133 to 333	12 houses (peak)

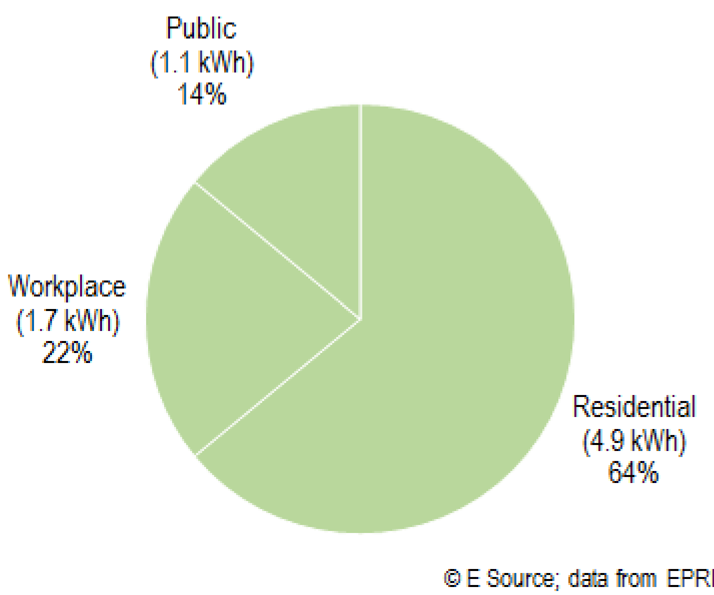
Notes: A = ampere; AC = alternating current; DC = direct current; V = volt.
a. Charge rate is indicative of the number of miles of driving range added per hour of charging.

Aside from the amount of time required to recharge a PEV, the other major distinguisher of EVSE is where the charging stations are located. The three most common locations for EVSE installation are in the home, at the workplace, and in public spaces such as parking lots, garages, and curbside. A variation on workplace charging is private stations used to recharge company-owned (rather than employee-owned) vehicles. It's now generally accepted that the majority of PEV charging events are expected to occur in the home. This is largely a matter of convenience—cars spend more time parked at home than anywhere else. According to the latest results from the US Department of Transportation's National Household Travel Survey (NHTS), the average vehicle in America is parked at home 66 percent of the time. Workplace charging is of secondary importance—vehicles are parked at their owners' workplace about 14 percent of the time. [1]

Though the average vehicle spends only a relatively small fraction of its life parked in public places, access to public charging could play a significant role in spurring adoption and consumer acceptance of PEVs. This rationale is commonly offered as justification for the funding of public initiatives to install PEV public charging infrastructure, even though equipment utilization factors have been minuscule so far. In the long run, the majority of PEV charging is expected to take place at home with some taking place in the workplace and relatively little occurring in public locations (**Figure 2**). [2]

FIGURE 2: PEV charging infrastructure is needed most in the home

For many years, researchers have insisted that PEV charging will largely take place in the home and, therefore, there will be only a limited demand for out-of-home charging stations. The Electric Power Research Institute's (EPRI's) findings for the "average" PEV driver suggest that a large majority of PEV recharge events are expected to occur either at home or at work. For the typical driver on the typical day, assuming they have access to charging at all parking locations, the usage shown here—in kilowatt-hours—illustrates how much energy they might use and where they would source it.



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APPLICATIONS

Despite the fact that most PEV charging takes place at home or work, a large majority of existing EVSE infrastructure—about 70 percent, with some variation by region—has been installed in public locations. [3] This imbalance is natural during early deployment because the visibility of public EVSE is expected to send a message that PEVs are well-supported; it's easy to justify the spending of government funds on broad-based public-infrastructure projects. Another contributing factor is the prevalent use of Level 1 charging in the home (without additional EVSE, using the charging cord that most new PEVs are sold with). Government-supported PEV infrastructure projects have played a critical role in keeping the nascent EVSE industry afloat, enabling numerous companies to remain in business despite limited growth in PEV sales and even more limited uptake of EVSE. In regions where government projects have deployed infrastructure, local utilities have played active supporting roles, though there remains relatively little incentive for direct utility investment.

Three overarching categories are used to describe most EVSE installations—residential, commercial, and public—but differences in use requirements and environmental conditions often call for the designation of more-granular application types. In residential settings, for example, an EVSE installation in a single-family home with an attached garage is very different from one installed in multifamily housing. For public charging, EVSE applications can include posts that serve PEVs in on-street parking, wall-mounted units in parking garages, and pad-mounted DC quick-charging (DCQ) stations. And for workplace charging, EVSE might be accessible to employees, customers, company fleet vehicles, or some combination of the three. As we see a greater variety in EVSE applications, there's growing awareness of the features that best support the nuanced requirements of each.

Residential, single-family. The classic home-charging scenario: PEV charging takes place at home where dedicated off-street parking, either in a garage or driveway, allows relative ease of access to an electrical outlet or installed EVSE. Variations include location (indoor versus outdoor), use of EVSE or Level 1 electrical outlet, maximum power draw (Level 1 or 2, based on vehicle and EVSE current limits), and other equipment-specific characteristics (such as efficiency, charge profile, and communications standard).

Residential, multifamily. In the case of multifamily housing, many of the conveniences found in single-family housing—including proximity, security, and dedicated ownership—no longer apply. Drivers may live in one unit, park near a different unit, and have their electricity metered in a third location. There are also limited incentives for property owners of multifamily units to install EVSE for their tenants. As such, standardization of EVSE installations in multifamily housing units has proved to be rather tricky. Existing installations have been made possible primarily through government incentives and EVSE installation programs. Although some utilities have been involved in projects to install infrastructure in multifamily housing, it's not cost-effective without government incentives.

Residential, on-street. So far, no major city in the US has successfully tackled the problem of permitted charging for on-street residential PEV parking. This is due in large part to laws and policies preventing residents from running electrical wires over or under a sidewalk or other public right-of-way. A local example: E Source's Chairman, Michael Shepard, has worked for several months with the city of Boulder to try to overcome this hurdle so that he can charge his PEV while parking on the street in front of his home.

Commercial, employee. This is the charging scenario commonly referred to as "workplace charging." Employers install EVSE or access to Level 1 outlets to encourage their employees to purchase PEVs or to allow them to charge their PEVs at work. Additional incentives may also include dedicated or preferential parking spots and free or discounted charging fees. Employers may choose to make some or all charging stations available to the public in addition to employees, particularly when employee usage is low and the location is appropriate.

Commercial, fleet. From the perspective of customer segmentation, this scenario most closely fits the description for a classic commercial charging application. In this case, the primary (if not exclusive) reason for installing EVSE is to recharge PEVs owned by the host company, as opposed to vehicles owned by its employees or customers. Unlike residential or employee charging, where similarly charged passenger cars are the norm, commercial fleet vehicle charging requirements may vary by vehicle type. For example, the electric forklift, a common type of PEV used in commercial applications, may require the use of specialized EVSE that offers recharge capabilities matched to vehicle workload. If the same company owned and operated a fleet of electric passenger vehicles, it would likely need an entirely different set of EVSE units to recharge those PEVs.

Public, on-street. In this application scenario, the EVSE is akin to a parking meter that users can plug a car into. In the future, it's possible that these two services—the metering of paid parking and PEV charging—could be integrated into a single piece of equipment and enforcement protocol. For the time being, most on-street EVSE are installed and maintained entirely independently from parking meters or other parking enforcement infrastructure. Though public on-street charging applications are similar in configuration to residential on-street parking, the permitting process for commercial entities to install EVSE is easy compared to the process for an individual trying to do so at home. Generally speaking, on-street EVSE installations are more susceptible to damage caused by vehicle collisions or vandalism, and damage-resistant EVSE installations may be prohibitively expensive.

Public, parking lot or garage. This PEV charging scenario entails the installation of EVSE in a publicly accessible parking area, such as a parking structure owned and operated by a company or municipality. If a fee is charged for parking, PEV recharging may be included in the parking fee or may require the payment of an additional fee. Parking structures that could be good candidates for EVSE installations include those located at restaurants, retail outlets, schools, and theaters. [4]

Public, service station. In this scenario, PEV charging takes place in a setting analogous to the gas station used by conventional vehicles. Where implemented, this application is likely to involve the installation of a DCQ or other "fast" recharge option. Even then, no PEV charging option is particularly fast when compared with refueling a gasoline vehicle. With this in mind, it may be best to avoid modeling PEV charging after gasoline refueling. The battery-swapping stations proposed by Better Place, a service provider for switchable-battery electric vehicles, are a variation on the PEV service station theme; unfortunately, the company has backed out of the North American market as of February 2013. [5]

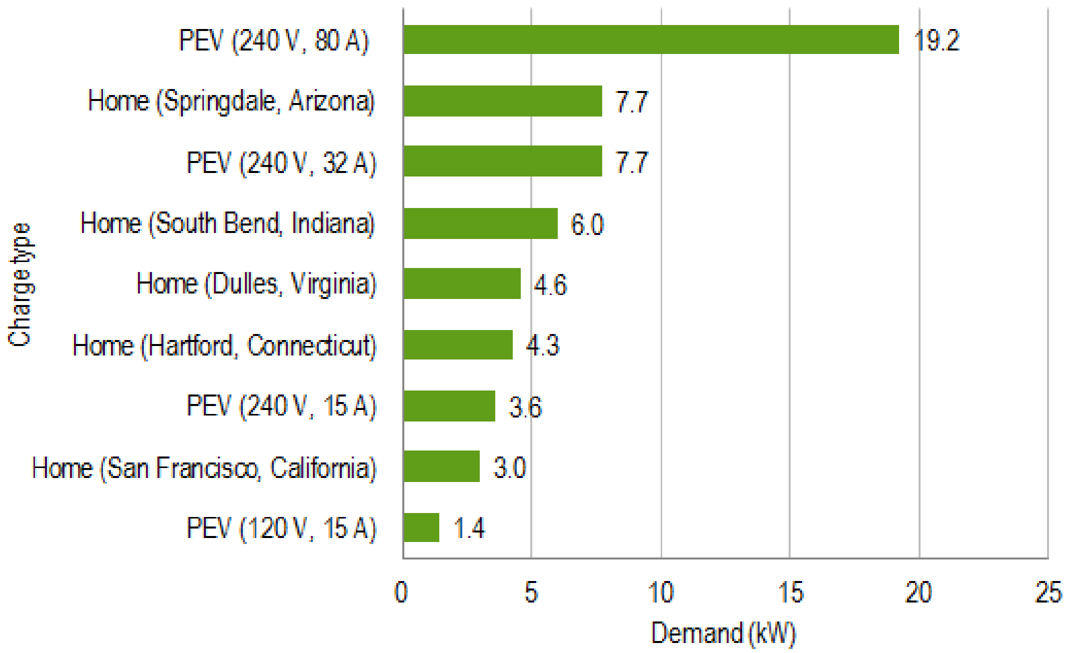
The degree to which EVSE is necessary to the deployment of PEVs remains a point of contention among researchers, advocates, skeptics, and other industry commentators. Though it may not always be convenient or practical, Level 1 PEV charging from a standard 120-volt electrical outlet is simple, costs little, and has a small impact because it doesn't require the purchase of additional equipment. PEV advocates have long claimed that an extensive EVSE network with fast-charging options is necessary to promote the mainstream deployment of PEVs, but their assertion remains unproven. In fact, there appears to be at least as much evidence to suggest just the opposite—that many PEV drivers are content plugging into a Level 1 outlet and have little need for EVSE. [6] As Mark Duvall, the director of electric transportation at the Electric Power Research Institute (EPRI), puts it, "Nothing is less important to the overall utility of PEVs than the rate at which they're charged." [7]

From the electric utility perspective, EVSE could be a blessing or a curse, depending on what the objective is. From the perspective of demand response and distributed storage, EVSE facilitates the aggregation of a larger dispatchable load and storage potential for a given number of vehicles. From the perspective of manageable load growth and grid impact, EVSE usage has the potential to increase peak load and accelerate the degradation of utility equipment—for many years, it has been speculated that "clustering" PEVs along a given feeder or around a distribution transformer could lead to early mechanical failure. And more recently, the issue of allowing sufficient time for transformers to cool off at night has been raised in relation to off-peak charging of PEVs. Of course, if vehicles are charged at AC Level 1 (up to 1.4 kilowatts [kW]), both of these concerns are less significant than if vehicles are charging at AC Level 2 (up to 6.6 kW). So far, though, neither PEV clustering nor nighttime transformer cool-off have materialized as significant problems for utilities.

Considering that a significant number of EVSE installations have already been done and that more will likely follow, intelligent control and management of EVSE—often referred to as "smart charging"—is perhaps the most reasonable option for minimizing risks and maximizing benefits of EVSE operation to the utility and PEV owner. [8] In its simplest form, smart charging might include the use of an inline or integrated timer that delays PEV charging until a later hour. More intelligence could also enable control of vehicle charging based on electricity pricing, outside air temperature, daily driving schedule, or any number of user-defined parameters. **Figure 3** shows the relative size of peak household demand in several US cities versus potential peak PEV demand for various recharging scenarios. [9] For more details on PEV smart charging, refer to the Performance section of this report.

FIGURE 3: The rate at which a PEV charges can drastically affect its relative grid impact

Depending on where the vehicle is located and the rate at which it's charged, a plug-in electric vehicle (PEV) might draw anywhere between 0.5 and 6.0 (or more) times the power of an average home. This variability in possible PEV demand is likely to complicate utility resource and capacity planning as more charging equipment is deployed across North America.



Notes: A = ampere; V = volt.
A value of 120 V indicates Level 1 charging; 240 V indicates Level 2.

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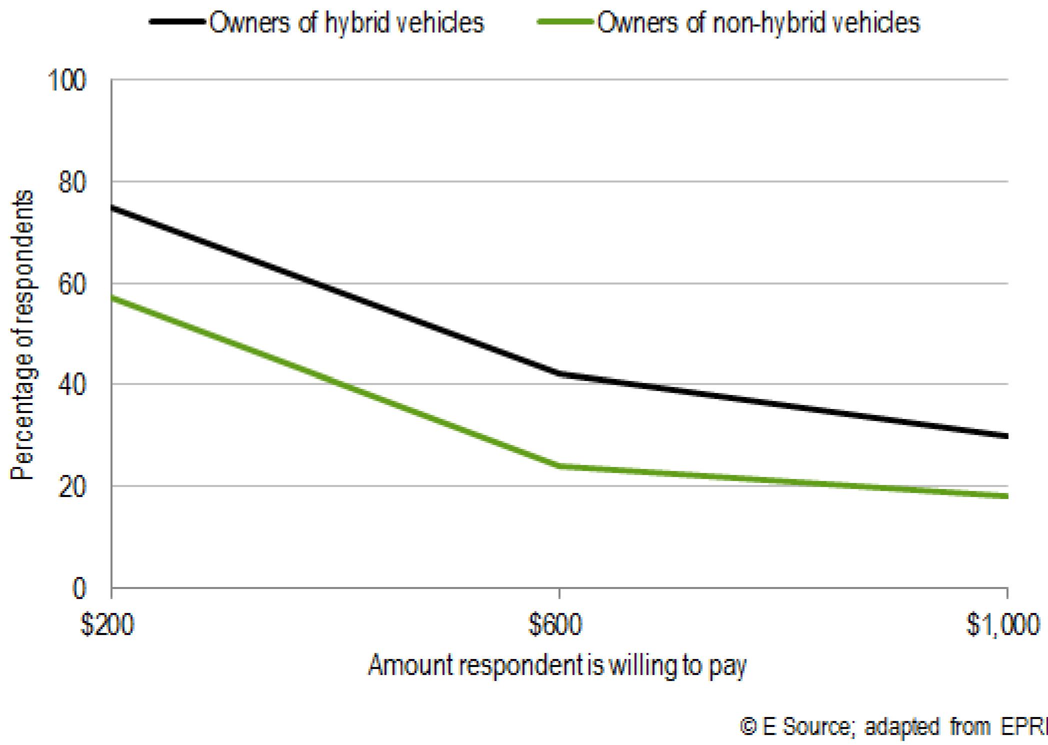
ECONOMICS

The high up-front cost of PEVs and their charging equipment is often cited as a significant barrier to market adoption. Like nearly all new consumer products, early models of EVSE have been very expensive, but those prices are starting to come down. Whether and when those prices will align with mainstream customer pricing expectations is yet to be seen.

Unlike the number of people who are willing to pay more for a plug-in vehicle, when it comes to EVSE products, most people seem to want to pay as little as possible. This is especially the case in residential settings where customers are not accustomed to purchasing separate chargers to operate their personal electronic devices. A study conducted by EPRI emphasizes this point: The willingness to pay for in-home EVSE products was low among the Southern California residents EPRI researchers surveyed; most people surveyed were only willing to pay between $200 and $400 (**Figure 4**). [10] That's less than the cost of the least expensive (Level 2) EVSE model on the market, not including installation costs and any associated permitting fees.

FIGURE 4: Most people aren't willing to pay what EVSE costs

The best market segment for the deployment of residential electric vehicle supply equipment (EVSE)—according to survey findings from the Electric Power Research Institute (EPRI)—is owners of hybrid electric vehicles. About 75 percent said they'd be willing to pay $200 for EVSE installation; far fewer were willing to pay $400 or more. A $200 price point is about half of what a low-cost Level 2 EVSE costs today, not including installation costs and permitting fees.

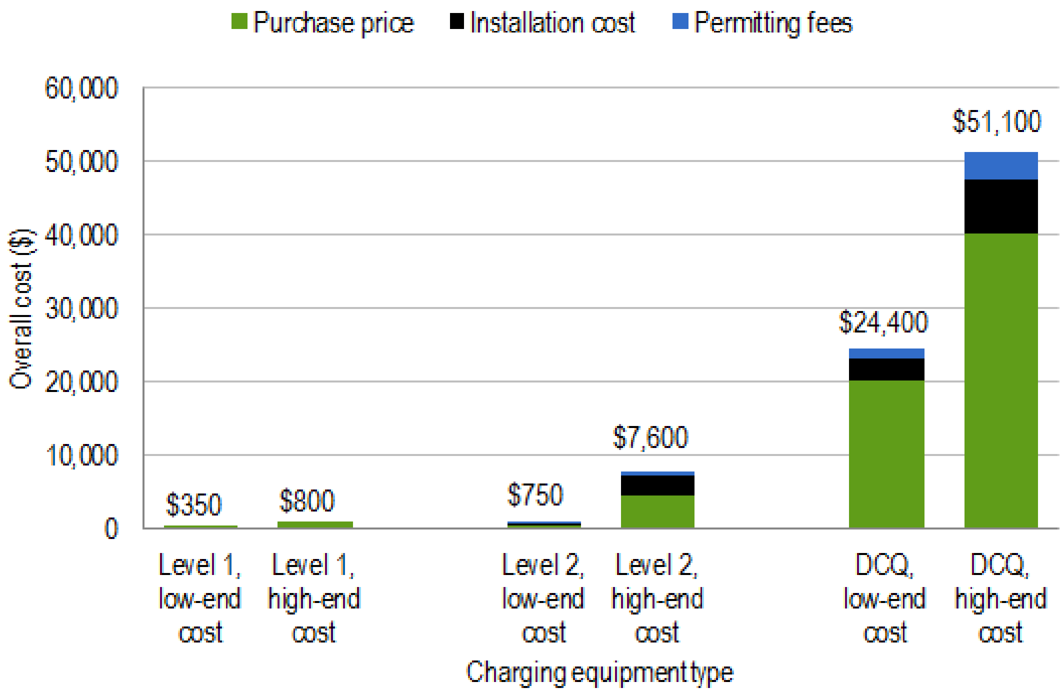


Up-Front Costs

The convenience of rapidly recharging an electric vehicle comes at a price (see **Figure 5**), and, as you saw in Figure 4, it may be a price that many are unwilling to pay. Although cost is something of a hindrance to widespread PEV acceptance—in the eyes of advocates, if not in reality—for utilities, it's probably a saving grace. If all PEVs were rapidly recharged all the time, it would almost certainly be detrimental to the distribution grid. So even though high equipment prices and installation costs may be holding back the EVSE market and, in turn, the adoption of PEVs into the mainstream market, it may not be a bad thing for utilities, at least for the time being.

FIGURE 5: Equipment that will charge a PEV in less time is more expensive

The cost of installing residential electric vehicle supply equipment (EVSE) typically ranges from about $800 to $1,500, but the cost of installing a public station can vary wildly from one instance to the next. In addition to variations in equipment and permitting fees, the physical attributes of each specific station location can play a major role. For example, if significant trenching or new lines are required, the cost can escalate quickly. Note that these costs don't include any additional station features, such as an overhead canopy, kiosk, or convenience store.



Notes: DCQ = direct-current quick charge; PEV = plug-in electric vehicle. Purchase of a new PEV typically includes a Level 1 cord set. Level 1 charging is at 120 volts (V), Level 2 is at 240 V, and DCQ is at 450 V or higher.

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Working to actively drive down the cost of EVSE is only an attractive prospect for utilities in two scenarios:

- If the utility gains the ability to dynamically control PEV charging (via demand response)
- If the utility can significantly inflate electricity pricing based on EVSE power draw (via time-of-use [TOU] rates).

So far, most existing TOU rates for PEV charging are unlikely to fully reflect the potential grid impact implications and the associated costs of high-power PEV charging: Although the highest PEV rate is up to $0.60 per kilowatt-hour (kWh) for on-peak charging, many rates are below $0.20/kWh. [11] Similarly, no existing demand-response program has retained the option to fully and dynamically control charging of the PEV via control of its EVSE.

Rebates for the purchase of EVSE in its classic form are unlikely to be a viable option, either now or in the future, because the use of EVSE will only increase the customer's overall electricity consumption (all else remaining equal). Therefore, it does not match the utility's demand-side management (DSM) goals for energy conservation. If it can be shown that PEV recharging is coincident with peak-demand periods, incentives for including EVSE in a demand-response program would seem warranted, but so far, there's evidence to suggest that isn't the case: By the time PEV drivers begin recharging at the end of the day, the peak has already passed. This phenomenon was cited by Russell Shaver, a consulting engineer for Austin Energy's Electric Vehicles&Emerging Technologies division, based on his early observations of his utility's smart charging pilot study. [12]

When a utility does expect PEV charging to significantly affect on-peak demands in its territory, it may make more sense to purchase EVSE and sell it to customers (or possibly even give the equipment away) than to have some other type of incentive. For commercial or public charging, it seems less likely that utilities will want to get into the business of selling or owning EVSE, but other incentives may be effective to reduce on-peak demand due to workplace or public charging. The two most likely approaches are dynamic pricing (higher on-peak electricity rates) and enrollment in a demand-response program. So far, there's not enough evidence to support the success of either of these approaches, though pilot projects are currently under way. [13]

It's possible that all EVSE of the future will integrate seamlessly into various smart grid communication networks via ZigBee, Wi-Fi, automated demand response, or other means, but we aren't there yet. [14] In the short run, direct utility communication with EVSE will be costly, requiring either a ZigBee connection through the utility smart meter or the adoption of an auxiliary communications hub. As such, it might not be a terrible idea for utilities to consider selling EVSE directly to their customers, or at least partnering with a company that can. Although examples of the latter approach (close partnerships) already exist for EVSE, [15] the former has yet to be tried. The direct sales model would be analogous to the involvement of some utilities in the in-home data display market—some utilities have partnered directly with manufacturers to specify and deliver their own "brand" of in-home displays at a lower cost than what is available for purchase by their customers. [16]

Government Incentives

Much like the deployment of EVSE itself, the availability of government money can be both a blessing and a curse. As a result of the government injection of money into the electric vehicle sector, many people can now afford to buy PEVs and have a growing number of places to charge them. On the EVSE network side, installations were made possible that would not otherwise have been and, as a result, the nationwide network of EVSE in the US has grown very quickly. On the downside, the cost of installing an EVSE unit without incentives remains prohibitive and the responsibility of operating and maintaining the equipment often resides with the site host. And although government-subsidized EVSE installation programs have certainly played a part in supporting PEV adoption, the cost-effectiveness of these roll-outs remains questionable given that the equipment is used relatively infrequently.

Canada has experienced regional and city-level EVSE deployments, but it has had no coordinated effort at the national level; two EVSE deployments were federally funded by the US government under the American Recovery and Reinvestment Act of 2009: the EV Project and ChargePoint America.

The EV Project. The EV Project, which is the most generously government-funded EVSE rollout (total project funding is $230 million), [17] is led by ECOtality (formerly eTec), a San Francisco–based original equipment manufacturer. The EV Project has focused primarily on public EVSE, and ECOtality is responsible for roughly 35 percent of the existing public EVSE installations so far—equipment that's referred to collectively as the Blink Network. Active utility participants in the EV Project include Portland General Electric and San Diego Gas&Electric, among others.

ECOtality is the number two installer in the US, behind ChargePoint. According to ECOtality's website, participants in the EV Project have installed 3,703 EVSE units at 1,471 unique charging locations (as of July 2013) and logged more than 90 million miles of electric driving so far. Drivers can find stations, get directions, and check EVSE operating status (such as "in use" or "available") via the EV Project's interactive station locator, BlinkMap. The EV Project posts PDFs of all the documents associated with its work—including quarterly reports, deployment guidelines, and long-range infrastructure plans—on its Project Documents page.

ChargePoint America. ChargePoint received far fewer federal dollars ($15 million) for its ChargePoint America deployment than were allotted to the EV Project, but ChargePoint's network is the largest in the US. Upon completion of its ChargePoint America initiative in April 2012, over 2,400 public and commercial EVSE units had been deployed as part of its network's more than 12,000 charging spots. ChargePoint (formerly Coulomb Technologies) has installed about 55 percent of the total public EVSE in the US so far. According to the company's website, nearly 41,000 drivers are currently utilizing the ChargePoint network and over 2.2 million charge events have been logged.

In March 2013, ChargePoint and ECOtality entered into an agreement to form a joint venture called Collaboratev. The objective of this collaborative is to allow customers to access both companies' networks—Blink and ChargePoint, which together constitute about 90 percent of the public EVSE infrastructure in the US [18] —with a single network membership. This will allow customers to use one authentication key for all stations, receive a single bill for all charge events, and access all networked station data from a single web portal or mobile application. Although this venture is expected to simplify the public charging experience for PEV drivers, some regulatory oversight will be needed to ensure that the new entity does not engage in price fixing or other market monopoly activities.

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PERFORMANCE

EVSE performs a fundamentally straightforward task: control the flow of electricity to the PEV's onboard charger. That's essentially all there is to it. As a result, steady-state EVSE efficiencies are typically very high (greater than 99 percent). Any additional features are included primarily to distinguish a given product in the marketplace by offering more control and convenience to the user. These upgrades are largely related to user experience via web portals and mobile devices, providing options such as the ability to check charge status, receive notifications, remotely control a charge event, manage payment for charge events, and set timers to start and stop charge events. Outside of payment management, most of these features are already available at the vehicle level using web-enabled applications for specific PEV models, which calls into question the need for and value of added EVSE functionality.

EVSE product features and performance are largely dictated by equipment standards rather than customer expectations. These standards are primarily intended to ensure safe operation without incident of electrocution or fire. Although there have been some reports of incompatibility between PEVs and EVSE units, [19] so far there have been no confirmed reports of damage to facilities or utility infrastructure. With the exception of wireless charging, most charging equipment operates very efficiently with relatively little variation from one piece of equipment to the next. For the most part, EVSE models are differentiated by their levels of customer feedback and interaction, which require networking and connectivity to collect and deliver real-time information to drivers.

Equipment Standards

In North America, there are five standards that are most pertinent to this equipment. Although other national and international standards have been developed and may apply to specific pieces of equipment or in specific countries or regions, these five standards cover most of the need-to-know issues related to form, functionality, communications, safety, and installation standardization for EVSE products.

SAE J1772. The Society for Automotive Engineers' standard covers vehicle-to-EVSE interconnection, in terms of both the physical interface and the communications protocol. It covers charging up to 240-volt AC (Levels 1 or 2) or 450-volt DC (DCQ) power at up to 80 amps. The form factor upon which this standard was based is a connector design from Japanese automotive parts supplier Yazaki. Though J1772-compliant Level 2 equipment can either be hardwired or cord-connected, for 240-volt systems to be pluggable the equipment must be sited indoors and include interlocking and de-energizing capabilities. Due to these requirements, most Level 2 EVSE is hardwired.

A "combination" J1772 connector and matching PEV receptacle is needed to enable DCQ charging; all vehicles built before 2013 are equipped with only the Level 2 receptacle. In Europe, a combination connector is now being used that's fully compatible with J1772. Conversely, the Nissan Leaf and Mitsubishi iMiEV were built to accommodate DCQ charging using a standard from the CHAdeMO Association that is not compatible with J1772. This standard was never adopted by US automakers and could eventually be phased out of use in North America.

Institute of Electrical and Electronics Engineers (IEEE) Protocol (P) 1901. The SAE J1772 pin configuration enables basic signaling between the EVSE and PEV to initiate and terminate charge events as needed, but it doesn't include any additional communications channels in the connector-to-receptacle design. To accommodate advanced communications options, IEEE P1901 standards for power line communication were adopted by SAE J1772 in 2012 in lieu of multiple SAE standards that were considered. (Wikipedia has a high-level, plain-English definition of IEEE P1901, if you want more details.)

IEEE P1901 is the standard protocol used for broadband over power line (BPL) devices operating at frequencies below 100 megahertz and at speeds of up to 500 megabits per second. It covers aspects of communications protocols that pertain to the physical and data-link layers. This standard serves as an overarching intersystem protocol that allows many signals from various devices to coexist on the electrical power lines without significant interference, despite close proximity of signal frequencies and narrow operating bandwidths.

IEEE P1905.1. This general standard applies broadly to the use and integration of multiple wired and wireless communications channels used in home area networks (HANs). These channels include various forms of connection, including Wi-Fi, power line communication, Ethernet, and multimedia over coaxial. IEEE P1905.1 defines the use of an abstraction layer to enable a global view of network topology independent of how many and what type of devices are on the network. In plain English, that means this standard was put in place to allow the many devices that exist within a HAN to communicate on the network with minimal interference.

Underwriters Laboratory (UL) Outline Investigation 2594. As with UL testing of any other consumer electronics product, UL 2594 describes the test conditions and minimum performance standards required for the safe operation of EVSE. This includes testing for general structural integrity, flammability, and electrical safety. And as with any other UL-listed device, the fact that a particular model of EVSE has been tested to UL safety and integrity standards does not ensure that it will operate according to manufacturer performance claims. Although UL listing is primarily an American standard, it has been harmonized with the Canadian Standards Association's (CSA's) test standard CSA C22.2 No. 280.

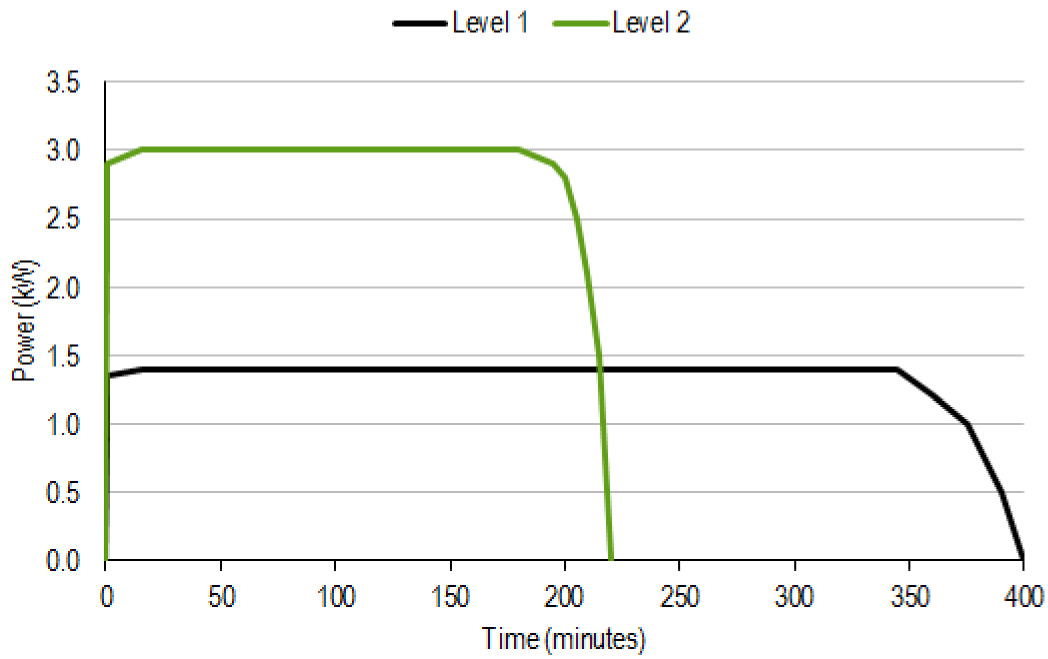
NFPA Standard 70. NFPA-70, also known as the National Electric Code, describes the safe installation of EVSE. Its most important information is its description of what to look for on product labels and how to safely install, connect or disconnect, energize or de-energize, operate, and locate equipment. Though NFPA-70 includes charge-coupler configuration and manufacturing descriptions, those aspects of EVSE product design are addressed by SAE J1772.

PEV Charging Profiles

In order to adequately plan for widespread PEV deployment, it's useful to know what the charge profile is likely to look like under different vehicle charging scenarios. Although it may seem like a safe assumption to conservatively assume that all EVSE units will charge at their maximum rated current all the time, in practice, EVSE typically plateaus at less than half its rated current and ramps up and down at the start and end of each charge event. This is due largely to onboard charger requirements that attempt to prevent damage to the PEV's batteries by limiting the maximum start-up, steady-state, and shut-down current levels. Idaho National Laboratory (INL) tests and documents EVSE performance, and its test documentation can be accessed from its EVSE Testing page. **Figure 6**, which is derived in part from INL's test results, depicts EVSE power draw generalized for a 2011 Chevrolet Volt charging at Levels 1 and 2.

FIGURE 6: EVSE typically operates at less than the rated maximum power draw

Due to the lower power rate and lack of offboard charge control, PEVs that charge at Level 1 experience relatively less ramping up and down of power. Assuming Level 2 charging at a constant power draw of 3 kW, it would take less than half the time for a full recharge relative to Level 1 charging at 1.4 kW. In actuality, both Level 1 and Level 2 charging tend to take a bit longer than expected due to the ramping up and down of their power draw at the beginning and end of a charge event.



Notes: EVSE = electric vehicle supply equipment; kW = kilowatt; PEV = plug-in electric vehicle.
This data is representative of an average power draw.

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In general, EVSE models tend to demonstrate similar power-ramping behavior across the board. Upon startup, most units take between 30 seconds and 1 minute to ramp up to their maximum power draw for a given charge event. Once the PEV's battery nears the upper end of its allowable charge capacity, the EVSE charge rate ramps down gradually over the remaining 15 to 20 minutes of the charge event. In between the start and end of the charge event—which is usually the majority of total charge time—constant (steady-state) power is drawn at the maximum allowable rate as determined by limits set by the PEV or EVSE, or by driver-specified requirements.

Conductive Versus Inductive Charging

Though wireless PEV charging can add convenience and high-tech appeal to the charging experience, it's not a worthwhile technology from the utility DSM perspective. "Wireless" is a colloquial term referring to inductive charging, in which electricity is transferred via inductors (coils) that are spaced far enough apart that no manual connection is required to initiate a charge event. By contrast, conductive charging—the standard practice—involves the physical interlocking of metal pins to allow current to flow directly from the EVSE to the vehicle's receptacle. Due to the conversion losses involved in inducing current flow from one coil to another, inductive charging is very inefficient: Its efficiency is 75 percent at best, where conductive charging can reach 99 percent efficiency or higher. Inductive charging equipment also tends to be much more expensive than conductive equipment for the same rated power. Based on cost and efficiency, there's little reason for utilities to take interest in inductive charging outside of responding to basic questions from their customers.

Operations and Maintenance

The costs of operating and maintaining EVSE will vary significantly by application and region, but the physical requirements are fairly universal. The primary objective of EVSE maintenance is to ensure the safe and continued operation of equipment by PEV drivers. Though most EVSE units in operation today are less than a few years old, reports of nonfunctioning equipment are already beginning to build up on PEV user forums and EVSE monitoring applications. Although outspoken PEV owners may appear as something of a nuisance to the industry, early adopters can aid EVSE hosts in identifying and addressing problems before they become widespread. From the perspective of supporting further PEV adoption, it's much better to have a PEV advocate identify a problem or potential hazard than to hear it from someone who isn't already sold on the technology.

In addition to users informing the host or the greater PEV community about a potential problem, automated notifications can be provided via fault detection or integrated messaging systems incorporated into the EVSE. Before installing equipment or advising customers on which equipment they should install, talk to the manufacturer or other EVSE owners or operators about anomaly detection features and their corresponding costs. For large or widely distributed EVSE networks, automated notifications may be desirable. However, once a notification has been received about a potential problem, someone will need to be sent into the field to check the status of the equipment. If no third-party maintenance agreement exists, the internal maintenance department will need to acquire EVSE test equipment, such as the EVE-100J from Gridtest Systems.

As with any piece of electrical equipment, the benefits of preventive maintenance are difficult to fully assess, but it could save on future costs and identify potential hazards. Outside of monitoring EVSE health using specialized test equipment, the maintenance of EVSE is fairly simple and straightforward. The parts that require routine inspection and maintenance are those that involve the most user interaction, primarily the charge cable and connector. If cords are regularly left on the ground or fall off their coiling mounts, a retractable cord may be a desirable feature that helps prevent equipment damage. When a charger is installed in an outdoor location that does not include protection from the elements, more-frequent inspections may be necessary to ensure that the equipment is operating properly; whenever possible, outdoor EVSE units should be mounted under a protective structure. In addition to the cord and connector, some equipment may include a user-interface display, a push-button panel, or a touch screen that should also be inspected on a regular basis for damage and functionality.

Networking and Connectivity

Drivers of conventional vehicles would never dream of accessing real-time operational data on local gas stations, but PEV drivers are demanding just that capability from their EVSE networks. This illustrates a major difference between recharging a PEV and refilling a conventional vehicle with gasoline: Due to the longer time required to recharge and the variation in EVSE locations, the tracking of station locations and usage status becomes much more important. This need is also driven by the relatively long distances between stations in some regions, coupled with the relatively short driving distance of most all-electric vehicles. Though the demand remains small and all-electric vehicle owners are the outspoken minority, that minority continues to grow; it's the driving force behind notable changes taking place in the EVSE market.

In the early EVSE deployments of the late 1990s and early 2000s—taking place mostly in California—public PEV charging stations weren't networked. Because real-time station data was not centrally collected and publicly distributed, it was impossible for drivers to know ahead of time whether the station would be available for them to charge upon arrival. For drivers away from home and low on charge, this presented a serious dilemma. A general etiquette arose among drivers (consisting largely of notes left on windshields), but the need for real-time information on station availability quickly became apparent.

By 2014, standards should also be in place for the customer side of EVSE operation, namely access via radio frequency identification (RFID) chips and customer billing requirements. RFID chips are often embedded in keychain fobs or swipe cards, and they are used by PEV drivers to access and pay for vehicle charging. Standardizing the use of RFID chips and communication between EVSE, PEVs, and the network has become a prerequisite to the development of a common protocol for assigning and authenticating station and user identities, among other things. [20] Presumably the formation of the Collaboratev joint venture between ChargePoint and ECOtality will help to further this effort.

Location and availability. Maps of public charging stations have existed for many years, but the reliability of their information was sometimes questionable. Although a station may in fact be located at the spot recorded on the map, it might not be operational when you need it. Or perhaps it only has one charge cord, a detail the station map failed to mention, and another vehicle is using it when you arrive. Having learned from these shortcomings, the station trackers of today include up-to-date information like street address, driving directions, number of EVSE units, number of charge cords, availability of units, reservation options, maximum charge rate, nearby businesses, and other related details. Station-tracking applications include Recargo, ChargePoint, BlinkMap, Open Charge Map, and Google Maps, among others. Less information is available for equipment that remains un-networked.

Revenue-grade metering and billing. For non-utility EVSE hosts such as municipalities or retail store operators, it can be challenging to collect money for PEV charging due to regulations that forbid the resale of electricity. To get around this roadblock, some public charging fees are incorporated into parking fees, but the majority of charging revenue is collected via network memberships. Prior to the establishment of EVSE networks and their corresponding membership subscriptions and fees, most charge events were provided to PEV drivers at no cost. For un-networked EVSE in some areas, this may still be the case.

Drivers pay for charging either on a schedule (such as monthly) or at the time they recharge their vehicle. Some subscriptions offer "all you can eat" charging options for a flat rate over a given period; others charge per event or based on time connected and charge rate. Of course, more-granular billing options require more-sophisticated networking capabilities to seamlessly connect drivers to their financial institutions, the station host, or a third-party station operator in real time. As a result, this has been one of the last features to come online in the wider deployment of EVSE infrastructure.

Smart charging options. From a battery preservation perspective, the "smartest" charging takes place at a mild charge rate and temperature. Because these requirements don't necessarily match user preferences or environmental conditions, the next best thing is dynamic management of either the PEV or EVSE to reduce the adverse affects of high-power charging. And though temperature may seem like an unrelated or uncontrollable factor, smart charging will play an important role on high-temperature days, both from the customer's perspective (battery life) and that of the utility (peaking demand).

The best approach to smart charging for the purposes of demand reduction or peak shifting will depend upon the equipment that's used as well as the preferences and behavior of customers who participate. If drivers arrive home later than the utility's peak demand window, there may be no need to involve them in smart-charging programs geared toward managing peak demand. [21] Regardless of when PEV drivers arrive home in the evenings, if they tend to be very well-behaved in terms of when they choose to recharge their vehicles, they won't be contributing to peak demand either. [22] Because most utilities probably won't opt to purchase and sell their own EVSE units or to communicate directly with all makes and models of PEV in their service territory—at least, not in the foreseeable future—use of an auxiliary device to cut off power to the EVSE may be warranted. [23]

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FOR MORE INFORMATION

Alternative Fuels Data Center, US Department of Energy, Energy Efficiency&Renewable Energy

Electric Vehicle Supply Equipment (EVSE) Testing, Idaho National Laboratory

Charging Station Technology Review for PEVs, Advanced Energy

Accessory Tracker, Plug In America

Find an EV Charger, GoElectricDrive.com

System and Network Providers, California Plug-in Electric Vehicle Collaborative

The Ultimate Guide to Electric Car Charging Networks, Plugincars.com

The Basics of Electric Vehicle Public Charging, Plugincars.com

EV Charging Stations: A Smart Choice for Your Business? E Source, *EMN-TB-4* (2012)

Electric Vehicle Rates, E Source, *EDRP-RB-13* (2012)

Plug-in Electric Vehicles, E Source, *TAS-RG-20* (2013)

E Source Electric Vehicle Publications, E Source, *EVG-RB-3* (2012)

Utility Industry Electric Vehicle Websites, E Source, *EVG-RB-2* (2012)

Non-E Source Electric Vehicle Publications, E Source, *EVG-RB-4* (2012)

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NOTES

1 US Department of Transportation, Federal Highway Administration, “Summary of Travel Trends: 2009 National Household Travel Survey” (2011), http://nhts.ornl.gov/2009/pub/stt.pdf.

2 Morgan Davis and Dan Bowermaster, ”Infrastructure Planning, Grid Impacts, and PEV Readiness for Ohio” (2012), Electric Power Research Institute (EPRI), www.driveelectricohio.org/wp-content/uploads/2012/11/EPRI_.pdf.

3 WXY Architecture + Urban Design and Energetics Inc., “Assessment of Current EVSE and EV Deployment” (2012), prepared for the New York State Energy Research and Development Authority and Transportation and Climate Initiative, www.transportationandclimate.org/sites/default/files/Assessment_of_EVSE_and_EV_Deployment.pdf.

4 John Krumm, “How People Use Their Vehicles: Statistics from the 2009 National Household Travel Survey” (2012), Microsoft Corp., written for SAE International, http://research.microsoft.com/en-us/um/people/jckrumm/Publications%202012/2012-01-0489%20SAE%20published.pdf.

5 Mike Millikin, “Better Place Winding Down Ops in North America and Australia, to Focus on Denmark and Israel” (2013), Green Car Congress, www.greencarcongress.com/2013/02/bp-20130207.html.

6 Mateo Jaramillo, “Tesla Motors,” presentation at the 2011 Utility Energy Forum (May 2011), www.utilityforum.org/2011/presentations/Fine.pdf.

7 Mark Duvall, “A Few Thoughts on the Early Plug-in Electric Vehicle Market,” EPRI, presentation at the 2011 Utility Energy Forum (May 2011), www.utilityforum.org/2011/presentations/Duvall.pdf.

8 Silver Spring Networks, “The Dollars—and Sense—of EV Smart Charging,” available from Energy Central (January 2011), www.energycentral.com/reference/whitepapers/103370/.

9 EPRI, “Transportation Electrification: A Technology Overview” (2011), Product ID 1021334, www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021334.

10 EPRI, “Characterizing Consumers’ Interest in and Infrastructure Expectations for Electric Vehicles: Research Design and Survey Results” (2010), Product ID 1021285, www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001021285.

11 Alexandra Behringer, “Electric Vehicle Rates,” E Source, *EDRP-RB-13* (2011), www.esource.com/members/EDRP-RB-13/Research_Brief/EV_Rates.

12 Russell Shaver (2013), Consulting Engineer, Electric Vehicles&Emerging Technologies, Austin Energy, russell.shaver@austinenergy.com.

13 Xcel Energy, “Electric Vehicle Charging Station (EVCS) Program,” www.xcelenergy.com/Save_Money_&_Energy/Find_a_Rebate/Electric_Vehicle_Charging_Station_Pilot_Program_-_CO (accessed May 2013); and Government Fleet, “New York State Awards $1.9M for Charging Stations to Municipalities&Public Entities” (June 6, 2012), www.government-fleet.com/channel/green-fleet/news/story/2012/06/new-york-state-awards-1-9m-for-charging-stations-to-municipalities-public-entities.aspx?prestitial=1.

14 Dwight MacCurdy, “SMUD Smart Charging Pilot Program,” Sacramento Municipal Utility District (SMUD), presentation at EPRI Infrastructure Working Council (March 2012), http://mydocs.epri.com/docs/publicmeetingmaterials/1203/JKN2SD37ZWH/D2_PEV_D2-2B_MacCurdy.pdf.

15 PR Newswire, “DTE Energy Selects SPX as Home Charging Installation Partner for Residential Plug-In Electric Vehicle Program,” press release (March 2011), www.prnewswire.com/news-releases/dte-energy-selects-spx-as-home-charging-installation-partner-for-residential-plug-in-electric-vehicle-program-117149563.html.

16 Craig Kuennen (2011), Glendale Water and Power, ckuennen@ci.glendale.ca.us.

17 John Smart and Stephen Schey, “Introduction to the EV Project: The Largest Deployment of Electric Vehicles and Electric Vehicle Charging Infrastructure Ever Undertaken,” Idaho National Laboratory and ECOtality (2010), http://www1.eere.energy.gov/vehiclesandfuels/avta/pdfs/evproj/intro_to_evproj.pdf.

18 Rebecca Smith, “Hybrid Car Charging Stations Team Up,” The Wall Street Journal (March 7, 2013), http://online.wsj.com/article/SB10001424127887324034804578344470323681946.html.

19 Jon Fingas, “Nissan Leaf, GE WattStation Embroiled in Charging Damage Shocker, Invite Other EV Puns (Update: Full GE Statement),” engadget (July 18, 2012), www.engadget.com/2012/07/18/nissan-leaf-ge-wattstation-embroiled-in-charging-damage-shocker/.

20 NEMA, “EVSE Network Interoperability Standards (an Overview),” presentation at the 2013 PEV Infrastructure Workshop (January 2013), www.energy.ca.gov/altfuels/notices/pev_infrastructure_workshop/2013-01-30_EVSE_Network_Interoperability_Standards.pdf.

21 Russell Shaver [12].

22 Freeman, Sullivan&Co., “First Year Evaluation for San Diego Gas&Electric’s Electric Vehicle Pilot,” prepared for San Diego Gas&Electric (2012), www.sdge.com/sites/default/files/regulatory/Attachment%204-SDG%26E%20ELECTRIC%20VEHICLE%20REPORT.pdf.

23 Xcel Energy [13].