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Federal Highway Administration

Final Report

**Feasibility and Implications of
Electric Vehicle (EV)
Deployment and
Infrastructure Development**

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16. Abstract Vehicle manufacturers and the traveling public are increasingly investing in plug-in hybrid and other electric vehicle (EV) technologies. The increased use of these technologies promises to yield multiple benefits, but it s also likely to affect the mission and programs of the Federal Highway Administration (FHWA), other U.S. Department of Transportation (U.S. DOT) modal administrations, state DOTs, and local transportation agencies. FHWA commissioned the Feasibility and Implications of EV Deployment and Infrastructure Development project ("the FHWA EV project") to help evaluate the prospects and expectations for short- and long-term deployment of plug-in electric vehicles (PEVs). The FHWA EV project analyzed the potential deployment of PEVs in the United States and their potential impact on the mission of FHWA, including financial implications for available highway revenues.					
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The research also benefited from a broad array of input from industry practitioners and experts. A series of expert interviews took place in late 2012 and early 2013 to collect information from state departments of transportation and other government agencies, electric vehicle manufacturers, electric vehicle supply equipment manufacturers and operators, industry stakeholders and non-governmental organizations, utilities, academia, and research institutions. Some of these experts also participated in an EV Forum, held on April 16, 2013 at the U.S. Department of Transportation (DOT) headquarters in Washington, D.C. The Forum convened approximately 30 practitioners in the energy, highway, and vehicle sectors to solicit expert input to the technical aspects of the project. The primary objective of the Forum was for FHWA and partner agencies to learn from experts working in the electric vehicle sector, and to gain a better understanding of the sector in order to better support the deployment of electric vehicles and associated infrastructure in the United States. The research team is indebted to these practitioners for the time and effort they contributed to the project.

Foreword

The Federal Highway Administration (FHWA) commissioned this research to better understand how an increasing use of electric vehicle technologies will affect our mission and programs, as well as those of other U.S. Department of Transportation (DOT) modal administrations. Existing highway infrastructure and funding is designed around a gasoline- and diesel-powered vehicle fleet. A substantial increase in the use of electric vehicles will create a significant difference in fueling practices and thus require new charging infrastructure. In addition, expanded electric vehicle use may have other implications for highway finance, safety approaches, and operations. FHWA is interested in whether existing infrastructure, programs, and practices pose impediments or could be modified to better facilitate and encourage the use of electric vehicles, which are one mechanism through which the transportation sector can reduce local on-road emissions and lower greenhouse gases.

This research project analyzed the potential deployment of electric vehicles in the United States and their potential impact on the mission of FHWA, including financial implications for available highway revenues. The results of the project will help transportation agencies to understand whether and how transportation policies, programs, infrastructure, services, funding models, and administrative activities may have to change as more electric vehicles are deployed on highways, roads, and streets—whether by simply responding to the increased vehicles, more actively supporting them, or proactively helping to accelerate their deployment.

This Final Report summarizes the information gathered during the various foundational research activities of the project, describes the development of eight long-term market penetration scenarios, presents the methodology used to undertake the scenario analysis, summarizes the findings of the analysis, and presents conclusions covering a range of possible “pathways” for FHWA and partner action, including possible additional research for consideration.

This publication is intended for use by FHWA personnel and the staff of other DOT modal administrations, state Department of Transportation personnel, the staff of other state, regional, and local government agencies working on electric vehicles, and others in the energy, highway, and vehicle sectors.

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EXECUTIVE SUMMARY

Vehicle manufacturers and the traveling public are increasingly investing in plug-in hybrid and other electric vehicle (EV)¹ technologies. The increased use of these technologies promises to yield multiple benefits, but is also likely to affect the mission and programs of the Federal Highway Administration (FHWA), other U.S. Department of Transportation (U.S. DOT) modal administrations, state DOTs, and local transportation agencies. In September of 2012, FHWA initiated the *Feasibility and Implications of EV Deployment and Infrastructure Development* project (“the FHWA EV project”) to help evaluate the prospects and expectations for short- and long-term deployment of plug-in electric vehicles (PEVs). The FHWA EV project analyzed the potential deployment of PEVs in the United States and their potential impact on the mission of FHWA, including financial implications for available highway revenues.

FOUNDATIONAL RESEARCH

This section summarizes the information gathered during the foundational research phase of the FHWA EV project, which included an extensive literature review, a series of expert interviews, a series of federal agency staff interviews, and an EV Forum convening more than 50 practitioners in the energy, highway, and vehicle sectors to provide input.

PEV characteristics

Types of PEV

PEVs can be classified into three general groups:

- Battery electric vehicles (BEVs).
- Plug-in hybrid electric vehicles (PHEVs).
- Range-extended hybrid electric vehicles (REEVs).

While BEVs are powered entirely by on-board batteries, PHEVs and REEVs have both electric motors and internal combustion engines (ICE), so they are forms of hybrid electric vehicles (HEVs). The drivetrains of PHEVs are typically derived from those of regular HEVs, and PHEVs generally favor battery power and engage the ICE as often as needed based on driving conditions. REEVs typically operate solely under battery power, and use the ICE only to extend the vehicle range once the battery is depleted.

¹ Unless otherwise specified, throughout this document the term Electric Vehicles (EVs) refers to the spectrum of vehicles that are powered at least in part by plugging into the electric power grid. EV configurations include pure battery electric vehicles (BEVs), plug-in electric vehicles (PEVs), plug-in hybrid electric vehicles (PHEVs), and range extended electric vehicles (REEVs). The terms EV and PEV are generally used interchangeably.

Battery characteristics

Batteries significantly affect the costs, performance, and development of PEVs. Current plug-in vehicles almost exclusively use lithium-ion (Li-ion) battery chemistries with energy densities in the range of 0.12–0.15 kWh/kg. It is generally expected that incremental improvements in battery technology will lead to densities approaching 0.20 kWh/kg. Additional improvements would require radical advances in technology and need to overcome a number of technical challenges. Battery life is generally assumed to be around 10 years, but is uncertain and depends on conditions during use. A typical vehicle battery pack has manufacturing costs between \$10,000 and \$20,000, but costs are dropping and projected to be around half of current values by 2020.

Other vehicle characteristics

Weight: BEVs are approximately 20% heavier than their ICE equivalents. PHEVs are also heavier, though by a smaller percentage.

Speed and acceleration: PEVs have better torque at low speeds than ICE vehicles, leading to potentially higher rates of acceleration. Top speeds are usually lower for electric vehicles.

Range: Typical actual driving range for BEVs is 40–120 miles, and BEVs are seen as an urban vehicle primarily used for intra-city travel and commuting. This may change if additional charging infrastructure outside of urban regions is installed.

Noise: Noise levels of PEVs are much lower than those of conventional ICE vehicles, especially at low speeds in urban areas. These low noise levels may pose a concern, as “silent” vehicles present a potential safety hazard for pedestrians.

Cost: PEV purchase prices are considerably higher compared to similar ICE cars, mainly due to the high cost of the batteries. PEV drivetrains are currently more expensive than conventional drivetrains, and for PHEVs and REEVs, are likely to remain so. Pure BEV drivetrains, however, are likely to become less expensive than ICE drivetrains over time, due to their relative simplicity. Electricity costs per mile to operate a PEV (in charge-depleting mode) are likely to remain much lower and less volatile than the fuel costs for ICE vehicles.

Driver characteristics and expectations

Private consumers considering the purchase of a PEV evaluate traditional factors such as cost, reliability, performance, and aesthetics, but also PEV-specific usability considerations related to ease of charging and battery performance. Early adopters’ reasons for EV purchases included symbolic values such as “a strong ethical belief to protect the environment or oppose war,” “a desire to reduce dependence on foreign oil,” “an assertion of individualism and to embrace new technology,” and “gaining social standing.” Communities and regions that include relatively large numbers of individuals who are collectively aware of these issues will likely see higher

levels of PEV deployment and earlier development of EV related infrastructure and other support, which will drive further adoption.

Studies of PEV purchasers show that:

- The majority of early adopters are male.
- Owners typically live in two-person households.
- Most also own a conventional, gasoline-powered vehicle and single-family home.
- Financial reasons have more weight in the purchase decision than other factors such as environmental protection.
- Those likely to purchase an EV were environmentally concerned.
- Respondents exhibited a very high frequency of online activities and use of associated technologies.

Fleets often feature characteristics that would make them potentially well suited for electrification, but private consumers have proven to be the main purchasers of PEVs to-date.

Charging stations

Charging station levels

Currently, there are three charging levels/rates available for Electric Vehicle Supply Equipment (EVSE, or “charging station”), the equipment used to deliver electricity to a PEV:

Level 1: Level 1 Alternating Current (AC) is compatible with all PEVs. This is the typical 120V AC plug home charging option. A charging station cord set is typically included with the purchase of the new vehicle, so that no additional charging equipment is required. Level 1 charging adds approximately 4–5 miles of range to a PEV per hour of charging time.

Level 2: Level 2 AC is compatible with all PEVs; it requires additional equipment and installation modifications by a trained, licenced electrician, and costs approximately \$2,000 when installed at a home using a 240V outlet. Level 2 equipment uses the same connector and adapter as Level 1 equipment. Based on the battery type and circuit capacity, Level 2 charging equipment adds about 10–20 miles of range per hour of charging time.

DC Fast charging: Direct Current (DC) Fast charging (also known as Level 3) is used to quickly charge BEVs. It is the most expensive option to purchase, install and operate because of more expensive parts and necessary electrical upgrades, and is unlikely to be available for home charging. A DC Fast charge can add 60–80 miles of range to a light-duty BEV in 20 minutes. Unlike Level 1 and 2 charging, there is no single agreed-upon standard for DC Fast chargers, but they do offer the possibility of being combined with off-grid electricity production, such as wind or solar power.

Charging station locations

The location of stations where users charge their BEVs is important and affects charging behavior, the economics of charging, and also planning for investment in charging infrastructure networks.

Home charging includes charging at single family homes, in the parking garages of multi-unit apartment complexes, and at on-street residential spaces. Home charging is expected to be a combination of Level 1 and Level 2 charging used to charge PEVs overnight. **Workplace charging** is expected to be Level 1 and Level 2 for daytime charging. Home and workplace charging represent the majority of charging events.

Public charging stations can increase the useful range of PEVs and reduce the amount of gasoline consumed by PHEVs and REEVs. The existence of public charging infrastructure may be important for reducing “range anxiety” and therefore instrumental to increasing the adoption of BEVs.

Publicly accessible local destinations include parking lots at local venues where the public spends multiple hours at a time or stays overnight. Examples include shopping malls, restaurants, tourist attractions, hotels, truck stops, public parks, park-and-ride lots, and government buildings. Such locations typically offer Level 2 charging. Charging locations on private property may impose constraints on some PEV owners (for example, limited business hours or patron use only), so there may be a need for additional charging stations that are on publicly accessible property.

Publicly accessible chargers on or near the Interstate Right of Way (ROW) can be located at rest areas or off-ROW commercial locations (e.g., travel plazas, truck stops, gas stations, and tribal rest areas), and may offer Level 2 or DC Fast charging. The practicality of levying a financial charge will need to be considered for some public charging business models. Rest areas are obviously an important potential location for publicly accessible chargers on or near the Interstate ROW, but without significant investment in infrastructure, policy/legal clarifications, and changes in rest area operational practices, the majority of Interstate charging will be most likely to occur at multi-use commercial facilities at Interstate exits, which offer existing food/retail services, good access, existing signage, and a robust electricity supply.

Charging station standards

Level 1 and Level 2 AC chargers are compatible with all PEVs, can be used at home, and follow the Society of Automotive Engineers (SAE) J1772 standard which is supported by all major vehicle and charging system manufacturers in the United States. For DC Fast charging, there are currently three different standards in the United States:

- **SAE Combo** Level 2 & DC, which was approved in October 2012.
- The Japan-based **CHAdeMO**.
- **Tesla Motors** proprietary standard.

Given these different standards, there may be future compatibility issues for high-current chargers.

Charging station business models

The PEV charging market is in an early stage and therefore highly volatile. There is uncertainty regarding which technical standards and business models will succeed. There are also many new companies entering the market. Several business models for charging stations are plausible, including subscription-based, pay-as-you-drive, or free charging at retail locations.

Demand for publicly accessible charging stations

The demand for installing publicly accessible charging stations depends on:

- The type of PEV (i.e., BEVs, PHEVs, or REEVs).
- The geographic distribution of current PEV users and future potential purchasers.
- Where the charging station is located—whether publicly accessible on or near the Interstate highway system, publicly accessible at local destinations away from the Interstate, or at home or work.

Demand considerations related to type of PEV: Drivers of PHEVs and REEVs do not have to use publicly accessible charging points if they have traveled beyond the battery's charge-depleting range, because these vehicles can use their ICE. Therefore, focusing on BEVs is the best approach for determining the implications for different travel markets and the demand for installing publicly accessible charging stations. Charging options away from home and work will be a critical factor in encouraging BEV use, particularly for longer trips. Quick and efficient charging will be most conveniently accomplished using a DC Fast charging system. This approach would require an approximately 24-minute charging window, in what is assumed to be a 30–40 minute stop in the near term, during which the vehicle will be charged sufficiently to travel about 60 more miles. While 30–40 minutes provides a reasonable duration for a break, drivers are unlikely to have frequent need for such a long break after driving only 60 miles on the Interstate. For charging at publicly accessible charging stations at local destinations, Level 2 charging may be sufficient. Adding approximately 30 miles of additional range could be accomplished in under two hours.

Demand considerations related to geographic distribution of PEV users and future potential purchasers: PEVs tend to be located in “hotspots” across the country. The concentration of PEV sales is influenced by political, cultural, economic, and geographic factors. Political factors include policy incentives such as local or state governmental tax credits, PEV use of high-occupancy vehicle (HOV) lanes, and building codes that accommodate the use of the vehicles. Temperate climates, flatter landscapes, and higher urban densities are more conducive to efficient PEV use—particularly BEVs. For example, in a study conducted by AAA, cold temperatures were shown to cause significant losses in range among PEVs. At 20 degrees Fahrenheit, PEVs exhibited a 57 percent loss in range compared to their operation at 75 degrees Fahrenheit. Oak Ridge National Laboratory found that at 20 degree Fahrenheit, ICE vehicle

efficiency dropped by 12 percent, and hybrids experienced a 31–34 percent decline (AAA, 2014). PEV range loss can also be attributed to powering the climate control system, but alternatives such as heated seats and preheating the vehicle during its charge prior to driving can reduce this impact. Current sales of PEVs tend to reflect these influences, with PEV sales clustered in temperate regions with substantial tax credits (e.g., California), and dense urban areas such as Washington, D.C., New York City, and Chicago.

Demand considerations related to location of charging stations: The various types of charging location are discussed above. Of these types, publicly accessible charging stations on or near the Interstate highway system are expected to represent a very small portion of all PEV charging initially. Therefore, based on demand alone, a broad network of charging stations across the Interstate highway system does not appear to be justified in the short-term. By 2030, we can expect to see both an increasing number of PEVs and an increasing number of intercity trips conducted using those PEVs. However, there are strong arguments in favor of promoting the development of an intercity network sooner, in advance of market forces. These arguments include:

- Reducing range anxiety to hasten the market transition between early adopters and the early majority, thereby accelerating PEV adoption.
- Improving the practicality of BEVs, and therefore their market share, advancing both climate change and energy conservation goals.
- Reducing the need for households to own a “backup” ICE vehicle, which is likely to reduce vehicle miles traveled (VMT) overall.
- Demonstrating the commitment of federal and state governments to vehicle electrification.

The Electric Power Research Institute (EPRI) has undertaken research to consider a U.S. nationwide EV charging network to serve 99% of the U.S. population with charging stations within 20 miles. The network includes several thousand “town locations” as well as 1,336 “safety locations” to cover major roadways across the United States. The proposed EPRI “safety” network is rather extensive, with coverage far larger than the Interstate system, and EPRI personnel have indicated that “accelerating deployment” may be a more appropriate term for this extensive network. A simple estimate of total infrastructure development cost for the proposed EPRI network is approximately \$67 million.

Role of utilities in charging

Utilities play a central and critical role in the deployment of PEVs and developing the associated infrastructure. Perhaps the greatest role any utility can play in this effort is providing public charging infrastructure and supporting the installation of private charging infrastructure. Utilities will also be responsible for the development of Smart Grid technologies, and can play a role beyond vehicle dealerships as a source of information on PEVs. Utilities are already actively engaging with PEV manufacturers and consumers, but are concerned about the variety of relevant state regulations, such as limitations on the ability of utilities to own and operate charging infrastructure. A study conducted by Ecotality and Idaho National Laboratory (INL)

found that PEV owners with time-of-use pricing generally began charging their vehicles around midnight, when lower rates are available (Ecotality and Idaho National Laboratory, 2013). Another study conducted by PEV Collaborative showed that households with PEVs tend to charge during off-peak periods, unless they have a solar photovoltaic (PV) system installed (Kurani et al., 2013), which makes them far more likely to charge at their convenience.

Future advancements in charging

Various possible future advancements in battery charging were identified in the foundational research. **Battery swapping** is appealing, as it overcomes the need to wait for charging to take place, but has yet to become widely implemented, and BetterPlace—the pioneer of BEV swapping stations—filed for bankruptcy in May of 2013. For home charging, future evolution of charging systems is likely to involve “**smart charging**”—i.e., charging during periods of low demand on the grid, or returning electricity from the battery back into the grid during periods of high demand (also known as vehicle-to-grid or V2G). A further advancement is **wireless (inductive) charging**, which uses an electromagnetic field to transfer electricity to a PEV without a cord, either when stationary (static wireless charging) or while the vehicle is in motion (dynamic wireless charging).

Highway design standards and infrastructure

A key premise of this analysis is that PEVs are, for the most part, replacements for conventional ICE vehicles. PEVs are not anticipated to create a separate new market, or lead to an expansion of the total number of vehicles that would otherwise be using the nation’s roads. Currently, PEV weights are approximately comparable to their ICE counterparts. Current design standards for infrastructure already accommodate PEVs. However, policies do exist (and could be expanded) to allow special use of certain infrastructure to encourage adoption—such as allowing PEVs to use High Occupancy Vehicle (HOV) lanes.

Safety, emergency services, and incident response

The most common safety concern raised in the expert interviews was the potential for PEVs to run out of battery power and break down in the middle of traffic, which would be mitigated by a safety network of publicly accessible charging along with standardized signage. Options currently available for PEVs that do become stranded include towing and charging. In the future, battery swapping may become an option, but currently this is not practical.

PEVs are unlikely to pose a greater risk of fire than gasoline powered autos. However, the National Fire Protection Association has produced online safety training for fire fighters and first responders.

Various safety groups have expressed concerns that the relative silence of a PEV’s electric motors presents a safety hazard to pedestrians and/or animals, potentially causing more collisions. The current trend appears to be moving towards a vehicle-based solution—i.e., fitting PEVs with a sound source.

When charging, making the necessary electric connections requires precautions, especially outdoors, where inclement weather and cable damage may occur. Cables may also present a trip hazard, and the possibility exists of PEV owners driving away while the charging cord is still attached. However, many of these potential concerns can be addressed through a combination of good design, the adoption of standards, and regulatory requirements.

Beyond the safety concerns listed above, there are various safety and human health benefits associated with the use of PEVs, including reduced local air toxics, reduced greenhouse gas (GHG) emissions, and reduced traffic noise.

Signage, information networks, and online mapping services

EV signage is defined in FHWA's Manual on Uniform Traffic Control Devices (MUTCD), but may need refinement to designate the level of the charging station. More detailed wayfinding signage may also be necessary, given that charging stations do not require a large retail complex that is easily spotted while driving. Finally, opportunities exist for online, mobile communication technologies to be used to augment standard roadside signage.

Energy Security

PEVs can support energy security in the United States by reducing the demand for and reliance on oil. The results are reduced oil prices, which protect the U.S. economy from the risk of short- and long-term increases in energy costs, and less exposure to the negative effects of a sudden disruption in oil supply. The U.S. Environmental Protection Agency (EPA) and Oak Ridge National Laboratory (ORNL) estimate that in 2025, the net energy security benefits of PEVs would be approximately \$1,000–2,000 per vehicle, in 2013 dollars, reflecting the combined benefits of reduced oil prices and protection from the negative impacts of oil supply disruption (Leiby et al., 2014).

Greenhouse gas benefits of PEVs

The GHG emissions linked to driving PEVs vary depending on the electric grid used to charge the vehicle, and in particular whether the grid primarily uses fossil fuels or renewables, such as wind and hydro. One study calculated that powering a PEV on electricity produced from 100% coal is equivalent to a gas-powered vehicle getting 30 mpg, whereas electricity produced by solar is equivalent to 500 mpg, with commensurate differences in GHG emissions. Notably, 83% of the U.S. population lives in areas where driving a PEV produces significant GHG reductions over the average gas vehicle, or is comparable to the highest efficiency gas vehicles (including hybrids), and this percentage is anticipated to increase over time. Additionally, the major PEV sales markets are primarily located in regions with less GHG-intense grids.

It is important to note that GHG emissions for vehicle ownership are the sum of the embodied emissions from vehicle manufacture, the fuel used to operate the vehicle, and the end of life disposal of the vehicle. The manufacture of the PEV battery produces more GHGs than the

manufacture of an internal combustion engine², which produces a “carbon debt” that the lower-GHG fuel must then pay back throughout the operation of the vehicle.

Policy context

Potential policy, regulatory, and statutory challenges to PEV deployment

Interstate system ROW rules: Title 23 of the U.S. Code, sub-section 111 (23 USC 111), prohibits the construction of automotive service stations and commercial establishments in the ROW of the Interstate system. This restriction includes commercial charging stations.

The Moving Ahead for Progress in the 21st Century Act (MAP-21) creates opportunities for federally financed PEV charging infrastructure at fringe or corridor parking facilities with Surface Transportation Program (STP) funds or at other locations with Congestion Mitigation and Air Quality (CMAQ) funds.

Other challenges: Regulations in many states require that companies that sell or resell electricity are classified as utilities and fall under the authority of the states' public utilities commissions. This classification creates difficulties for businesses that want to develop onsite public, fee-for-service charging stations for use by their customers or employees. Additionally, prospective PEV owners must have home charging stations installed and permitted, which is considered a barrier to consumer adoption of PEVs. Finally, gas tax revenues are down in inflation-adjusted terms, and a major shift away from ICE vehicles to PEVs would further accelerate existing declines in gas tax revenues.

Indirect policy support for PEVs

Corporate average fuel economy (CAFE) and GHG emissions standards drive the introduction of new technologies for conventional and hybrid vehicles and may increase the market share of advanced technology vehicles like PEVs. A few states have adopted or are in the process of adopting a Low Carbon Fuel Standard (LCFS) or a Clean Fuel Standard (CFS). LCFS programs require fuel producers and importers to reduce the GHG intensity of transportation fuels, which can be accomplished by increasing the use of electricity as a transportation fuel. Zero Emission Vehicle (ZEV) rules are intended to make pollution-free vehicles available at a commercial scale as quickly as possible. California's ZEV rules (and the 11 other states that have adopted them) require the largest auto manufacturers to earn increasing amounts of ZEV credits by providing the public with fuel cell vehicles, BEVs, PHEVs, or advanced hybrids. The rules require that by 2025, ZEV and PHEV sales should represent 15% of new vehicle sales.

Direct incentives for PEVs

² Table 7 of the main report gives the energy used in vehicle production as approximately 1,200 Btu per mile for a conventional ICE vehicle. If 20% of this is the energy used in the production of the engine, then this is 240 Btu per mile. The same table gives the energy used in battery production as 317 Btu per mile, around a third higher.

A federal tax credit of \$2,500–\$7,500 (depending on the battery size) is available for purchasers of PEVs. This tax credit is the biggest financial incentive available to PEV-buying consumers in the United States and is considered a key instrument for encouraging the purchase of PEVs. More than a dozen states also provide financial incentives, typically state tax credits. Several states allow single-occupancy vehicle (SOV) EV drivers access to HOV lanes. Arizona allows alternative fuel vehicles to park in areas designated for carpools. Multiple states allow emission test exemptions for alternative fuel vehicles.

Case studies of EV deployment

Four case studies of EV deployment were undertaken as part of the foundational research, as follows:

1. Oregon's Interstate-5 corridor (including Portland, Salem, Corvallis, Eugene).
2. Texas Greater Houston area.
3. North Carolina Greater Charlotte region.
4. California Bay and Monterey Bay area.

These case studies are provided in Appendix F and summarized below.

Oregon's Interstate-5 Corridor (including Portland, Salem, Corvallis, Eugene)

The bulk of EV deployment initiatives in Oregon have focused on the construction of charging stations along the Interstate-5 corridor, which stretches North-to-South along the western edge of the state approximately 50 miles from the Pacific coast, and includes the cities of Portland, Salem, Corvallis, and Eugene. Oregon's state government has led much of the planning for EV charging infrastructure and coordinated much of the subsequent deployment activity to date. In 2010 the Governor appointed a Transportation Electrification Executive Council (TEEC) composed of representatives from the EV industry, utilities, higher education, and local and state governments, to lead the development of an EV-readiness strategic plan for the state. The plan focuses on integrating existing PEV-readiness efforts, developing the statewide PEV market, and identifying specific programmatic needs in four priority areas: infrastructure deployment, policy support, communication and outreach, and engagement with energy utilities.

ARRA funding enabled the installation of DC Fast charging stations at 10 key intersections along the I-5 corridor in southern Oregon, creating over 200 "PEV-ready" miles that will eventually form part of the West Coast Green Highway, an envisioned network providing continuous infrastructure for alternatively-powered vehicles from Canada to Mexico. In 2013 and 2014 ODOT used U.S. DOT Transportation Investment Generating Economic Recovery (TIGER) funding to further expand DC Fast charging infrastructure, installing 33 additional DC Fast charging stations along other adjacent travel corridors. Oregon was also one of six states chosen to participate in the U.S. DOE's *EV Project* to install residential, workplace, and municipal Level 2 charging stations across the state. By September 2014 the DOE's Alternative Fuels Data Center website listed more than 370 publicly accessible charging stations in Oregon.

State policy support for EV deployment has included legislative action allowing state agencies to install EV charging equipment on state-owned premises, and a ruling from the Oregon Public Utility Commission that individual providers of EV charging services are not subject to OPUC regulation under Oregon statute. After years of consideration, Oregon is also the first state in the nation to have established a road usage charge system for transportation funding – for now a voluntary, opt-in alternative to the gasoline tax, which may lay the groundwork for further transportation funding innovation in the years to come.

EV readiness in Oregon has been further bolstered by coordination and member-training initiatives from key industry stakeholder groups representing electrical workers, automotive dealerships, emergency first responders, and electric utility employees. AAA has even launched a pilot program in Portland offering emergency roadside-charging services to EVs in the form of a specialized truck with an on-board generator and both DC Fast and Level 2 charging equipment.

Texas Greater Houston Area

The City of Houston has led EV infrastructure planning in the seven-county Greater Houston area, with funding support from the U.S. DOE's EV Project and the William J. Clinton Foundation. Houston is preparing for strong potential growth in the local EV market due especially to the size of the overall vehicle market in the area around Houston – the fourth largest city in the United States – and by the severity of local air quality issues, mitigation of which could be helped by the adoption of zero-emission vehicles.

The City's EV infrastructure planning efforts have focused on both detailed local analysis and long-range planning for an EV charging network that can provide sufficiently many public charging stations to meet the anticipated level of demand. Extensive analysis of demographic information, employment data, commuting and other travel patterns, land use projections, and broad stakeholder input was conducted to calculate the eventual appropriate densities of EV charging equipment, and optimal locations for future public Level 2 and DC Fast charging stations.

Actual charging infrastructure deployment, supported by the City of Houston's 2010 release of EV Charging Infrastructure Deployment Guidelines, has been led by multiple private-sector actors, some independently and some in partnership with the City. More than 250 public charging stations had been installed in the greater Houston area by September 2014, and the city projects the eventual installation of up to 1,000 publicly accessible Level 2 charging stations, and up to 750 DC Fast chargers, by the year 2020. Houston has also incorporated more than 90 electric vehicles into its municipal fleet, and installed associated charging stations, some of them open to public use.

In 2012 the U.S. DOE funded a Texas Triangle Plug-in Electric Vehicle Readiness Plan, exploring issues of EVSE deployment in the areas between the major cities of Houston, Dallas-Fort Worth, and San Antonio – including interstate highway corridors and many small and medium-size cities. The plan's basic conclusion is that without specific action and investment,

EV charging infrastructure will not grow sufficiently over the next five years for drivers of battery electric vehicles (BEVs) to comfortably make intercity trips between the major cities in the Texas Triangle.

North Carolina Greater Charlotte Area

The nine-county Greater Charlotte region encompasses 74 municipalities, including North Carolina's largest city, and possesses many attributes that may support significant growth in electric vehicle (EV) adoption in the region: high projected population growth (to 3.5 million people in the next 20 years); a strong local business community, including the headquarters of 10 Fortune 500 companies; high engagement in EV issues by local electric utilities, municipal governments, and many energy-focused businesses; and a high density of hybrid vehicle ownership, a leading indicator of consumer interest in plug-in electric vehicles (PEVs).

EV readiness planning efforts in the region have been led by many sets of actors at the state, regional, and local levels, in many cases with federal funding. Programs funded by the NC Department of Commerce and the U.S. DOE collaborated a Plug-In Electric Roadmap for North Carolina, which has heavily informed community-level EV readiness planning in Greater Charlotte. The Charlotte Regional Electric Vehicle Advisory Commission (REVAC), comprised of private and public-sector stakeholders considered key to EV deployment in the nine-county area, has focused on engaging four key barriers to developing a network of charging stations that would EV advance adoption: the lack of DC Fast chargers in and between metro areas; a lack of awareness of existing charging infrastructure; the cost of installing EV infrastructure; and the absence of charging station infrastructure within long-range transportation plans. Regional and local efforts have often incorporated a focus on public outreach and communication about EVs in general, as well as on specialized training sessions for emergency first responders, fleet managers, and other municipal employees.

Much of the existing EV infrastructure in the Greater Charlotte region has been deployed by individual municipalities and local businesses, with some of the largest efforts by the City of Charlotte, Nissan North America, and Duke Energy. Still, EV adoption in the region is at an early stage. Between August 2012 and March 2014, PEV registrations in greater Charlotte increased from 191 to 544; the Electric Power Research Institute (EPRI) projects that the nine-county greater Charlotte region will have 15,000 PEVs in service by the end of 2020. One issue identified in various Greater Charlotte area efforts is that of interoperability: how to standardize and communicate information about the variety of charging station locations and technologies available. Many current EV charging networks require a subscription to use, and not all types of chargers work universally with all models of electric vehicles. No public database definitively lists all charging station locations in North Carolina, although the U.S. DOE's Alternative Fuels Data Center (AFDC) tracks many sites, listing 219 stations as of September 2014 – 59 of them within 25 miles of Charlotte. Many private charging networks maintain their own sites independently, and may not be listed on the AFDC site; at the time of the greater Charlotte PEV Readiness Plan's assessment in February 2013, the authors tallied 152 EV charging stations installed at publicly available locations in greater Charlotte, and an additional 112 at private corporations for employees.

Private-sector engagement with EV development in North Carolina extends to the state's three investor-owned electric utilities, all of which have taken substantial steps toward EV readiness. These include research and EV pilot programs to evaluate charging technologies, charging behavior of PEV drivers, the likely electric-grid impacts of the proliferation of charging equipment, ways to incentivize off-peak charging, approaches to data collection around EV equipment installation, and necessary changes to customer service plans and communication materials.

California Bay and Monterey Bay Area

Efforts to support the adoption of electric vehicles (EVs) in California—the largest automotive market in the nation—have been supported by organizations at a variety of statewide, regional, and municipal levels. The Bay Area Air Quality Management District (BAAQMD) is the public agency entrusted with regulating stationary sources of air pollution in the region around San Francisco Bay, and has led or coordinated much of the extensive electric vehicle readiness planning work for both the Bay Area and the Monterey Bay Area immediately to the south. With state and federal support, the BAAQMD produced a PEV Readiness Plan for the region in late 2012, including extensive assessment of existing PEV ownership and barriers to further PEV deployment, and identification of potential sites for regional charging infrastructure. The Plan, and a followup Local Best Practices Document, also includes extensive guidance for cities and counties in the region and discusses implications for areas such as zoning, parking rules, and local ordinances; building codes; construction, permitting, and inspection; training and education of key stakeholders and of consumers; and grid and utility impacts of PEV deployment.

Subsequent EV readiness initiatives have been conducted by many municipalities with support from a wide range of stakeholders including researchers, utilities, and members of the PEV industry. The Bay Area and Monterey Bay Area PEV Readiness Plan assessed 11 separate EV charging infrastructure deployment initiatives in the region as of November 2012, and calculated approximately 4,000 residential Level 2 chargers, 1,500 non-residential Level 2 chargers, and 123 DC Fast chargers across the Bay Area and Monterey Bay Area. Inter-city infrastructure development efforts in the region are also underway, with the California Electric Commission CEC awarding more than \$17.4 million in grants to deploy charging equipment across the state. The Bay Area has the highest number of electric vehicles deployed among the 22 regions participating in U.S. DOE's national EV Project. Although the 12 counties comprise approximately 17 percent of California's population, their adoption rate of PEVs is approximately 40 percent of all PEVs sold across the state. Plug-in vehicle sales statewide more than doubled in 2014, to surpass 100,000 vehicles sold since 2010.

An extensive set of state-level policies support and incentivize the growth of PEV adoption in California, including consumer rebate programs, requirements for EV charging infrastructure in certain new and existing building development, and a requirement that all EV charging stations in the state allow any compatible vehicle to plug in and charge, rather than requiring a subscription or network membership. On the local level, many Bay Area municipalities have been modifying permitting and inspection processes, building and zoning codes, and other local-

level policies to ease the process of installing both residential and commercial electric vehicle charging equipment.

All major California electric utilities have PEV infrastructure programs in place that typically involve working with city officials to develop residential charging station procedures, planning for local infrastructure enhancements, and working in partnerships to pilot and demonstrate public infrastructure programs. Utilities and other regional entities involved in EV planning efforts maintain dedicated websites to educate the public about EVs, and multiple regional initiatives currently offer online and in-person training opportunities to educate stakeholders on the more technical aspects of PEV readiness and deployment – including specialized training for licensed electricians and emergency first responders.

DEVELOPMENT AND ANALYSIS OF PEV DEPLOYMENT SCENARIOS

This section provides the background to the development of eight credible PEV deployment scenarios, and presents the key interim analysis parameters and results generated based on the scenarios.

Background

PEV sales are currently in their infancy, but are increasing rapidly. Approximately 95,000 PEVs were sold in the United States in 2012. U.S. DOE reported that the estimated cumulative U.S. supply of electric vehicles through to 2015 will exceed one million vehicles, and while industry projections strongly suggest that the market supply should be available to meet this target, this does not appear likely based on current sales trends at the time of writing. In the slightly longer term, forecasts for PEV market growth over the next decade vary widely, and diverge even more for the 2020–2050 timeframe, as shown in Table 1.

Table 1: Forecasts of the fleet population of PEVs from a range of sources

Forecaster	Prediction	Year	Notes
Pike Research (Pike Research, 2011)	1.0 M	2017	-
CAR 2010 (Center for Automotive Research, 2011a)	0.47 M	2015	-
Zpryme (Zpryme, 2010)	0.73 M	2016	-
DOE Annual Energy outlook 2013 (EIA 2013)	0.91 M 3.32 M (1.27% of all LDV) 6.32 M (2.23% of all LDV)	2020 2030 2040	Used as Scenario 1
MIT 2007 (MIT, 2007)	17.3 M (7.5% of all LDV, 230 M)	2035	-
National Academy of Sciences (National Academy of Sciences, 2010)	Approx. 1 M 13 M 100 M	2020 2030 2050	Probable penetration scenario ³
Berkley, 2009 (Center for Entrepreneurship & Technology University of California, 2009)	0.8–3.2 M 8–21 M 65–100 M 180–240 M	2015 2020 2030 2050	-
EPRI (2012 COG EV Taskforce presentation)	0.8–3.2 M 2.5–8 M 12.5–50 M	2015 2020 2030	-
IEA Technology roadmap (European Green Cars Initiative, 2010)	50% of light duty sales, i.e., fleet of approximately 100 M	2050	-

Pike Research projects that California, New York, Florida, Texas, and Hawaii are expected to lead in PEV sales between 2012 and 2020. The top five metropolitan statistical areas (MSAs) for PEV sales are expected to be New York City, Los Angeles, San Francisco, Seattle, and Portland, OR.

³ The source provides two projections for the numbers of PHEVs in the U.S. light-duty fleet. The numbers given here reflect what is described as the “Probable rate of penetration” A “Maximum practical penetration” (with 240 million vehicles in the fleet by 2050) is not included in the above table.

AEO 2013 projections indicate that the fraction of all PEVs anticipated to be purely electric vehicles will be 7% in 2020, 14.5% in 2030, and 23.5% in 2040.

The future deployment of charging station infrastructure is as difficult to predict as future deployment numbers of PEVs. Pike Research predicts that global charging station sales will steadily climb at a compound annual growth rate of 37% from 2012 to 2020. A recent report by Frost and Sullivan estimated a total of 4.1 million charging station units in North America by 2017, with Level 1 residential charging stations anticipated to represent 71% of these units, Level 2 representing 27% of installations, and DC Fast chargers representing only 2% of installations. Home charging is expected to represent 87% of all EV charging. Pike Research predicts that by 2020, the charging station market in the United States will be focused in a handful of states, largely those with the greatest PEV market.

Vehicle analysis

PEV uptake and composition of PEV fleet

The projected PEV fleet numbers used in each scenario are shown in Figure 1, and the composition of the PEV fleet in terms of 10 distinct vehicle categories shown in Figure 2. The scenarios are intended to describe plausible visions of PEV deployment in the United States for 2020, 2030, 2040, and 2050, ranging from conservative to very ambitious. All of the scenarios can be viewed as incremental developments of the existing factors that influence deployment, and do not include game-changing phenomena that would accelerate growth of PEV sales, such as rapid demand increases, dramatic price reductions, extreme technological changes, or aggressive regulatory changes.

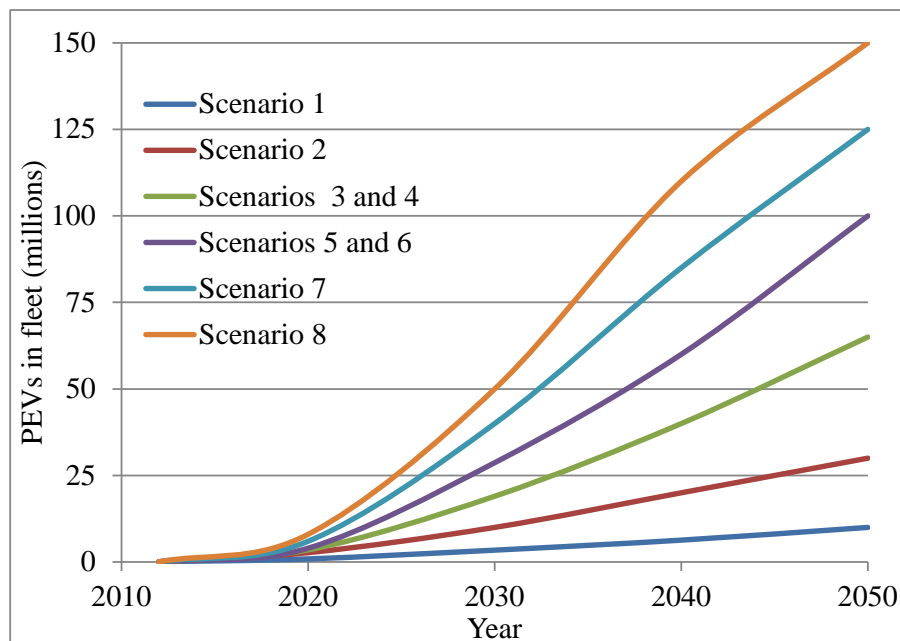


Figure 1: Projected PEV population by deployment scenario

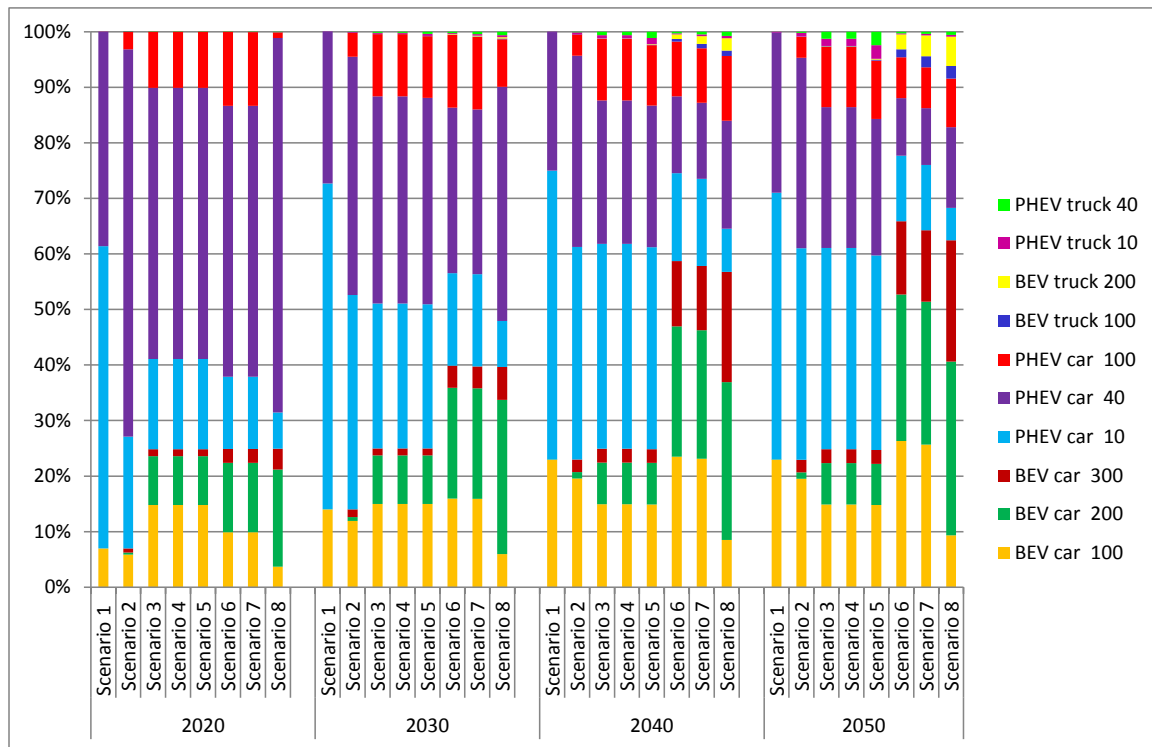


Figure 2: Composition of the PEV for each scenario-year combination

A high level description for each of the eight scenarios is given below:

- Scenario 1 Baseline scenario; Based on DOE AEO 2013 assumptions
- Scenario 2 Modest addition growth; First step up between DOE AEO 2013 and EPRI “medium growth” scenario
- Scenario 3 Larger addition growth; Second step up between DOE AEO 2013 and EPRI “medium growth” scenario
- Scenario 4 Larger growth in both EV numbers, as for Scenario 3, and in Interstate highway charging
- Scenario 5 Growth to values predicted in the EPRI “medium growth” scenario
- Scenario 6 Growth to values predicted in the EPRI “medium growth” scenario with EV vehicles having an extended range
- Scenario 7 Growth to EV numbers between the EPRI “medium growth” and “high growth” scenario

Scenario 8 Growth to values predicted in the EPRI “high growth” scenario, with EV vehicles having an extended range, an making increased use of highway (rather than “residential”) charging

PEV fleet annual electricity consumption

The average miles per year for each category of PEVs and the average electric charge required to drive each mile were established and combined with the PEV deployment scenario data to calculate the PEV fleet’s annual electricity consumption, shown in Figure 3, for each of the eight scenarios and four target years.

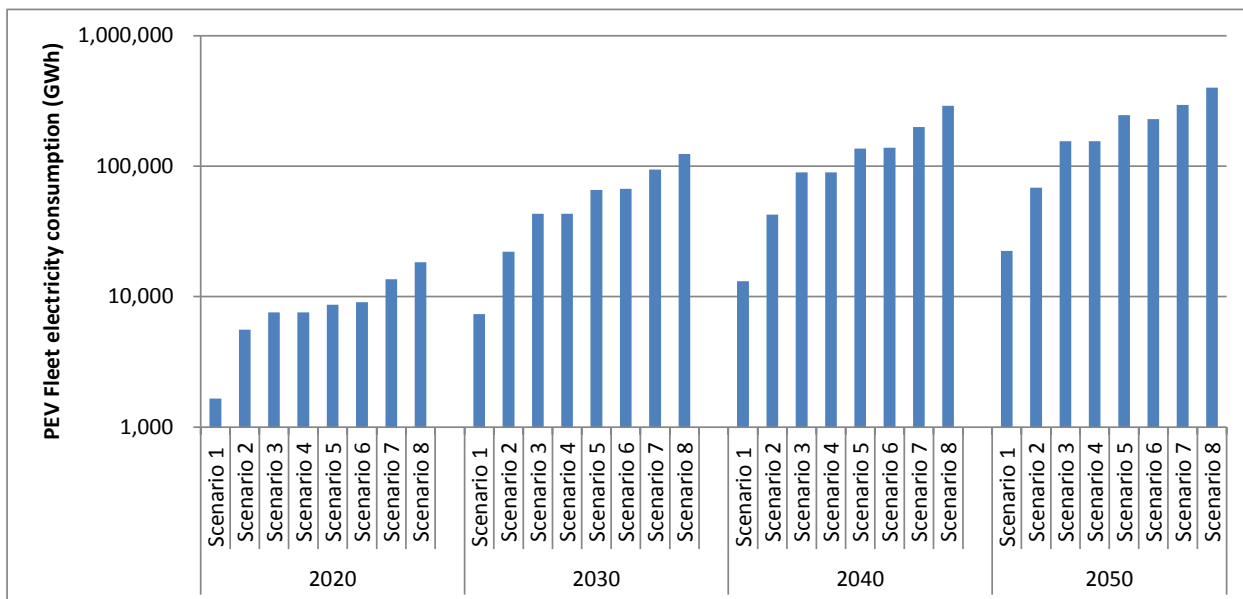


Figure 3: Annual PEV fleet electricity consumption by scenario

Values range from approximately 1,650 GWh for Scenario 1 in 2020, to approximately 400,000 GWh for Scenario 8 in 2050.

Average volume of gasoline displaced per EV-mile

The type of fossil fuel displaced by PEVs is assumed to be predominantly gasoline. The analysis assumes that 13 kWh of electricity is equivalent to one gallon of gasoline for all PEVs and vehicle classes in 2012, with a plausible range of 9–17 kWh/gallon. Additionally, the average volume of gasoline displaced per EV mile driven is anticipated to vary over time, as shown in Table 2. This is caused by changes in the projected efficiency of both gasoline and electric vehicles.

Table 2: Ratio of electricity to gasoline consumption

Year	2012	2020	2030	2040	2050
Energy equivalence kWh per gallon of gasoline	13.0	14.6	17.5	18.3	16.7

Average Quantities of gasoline displaced by the PEV fleet

Figure 4 presents the gallons of gasoline displaced by the PEV fleet.

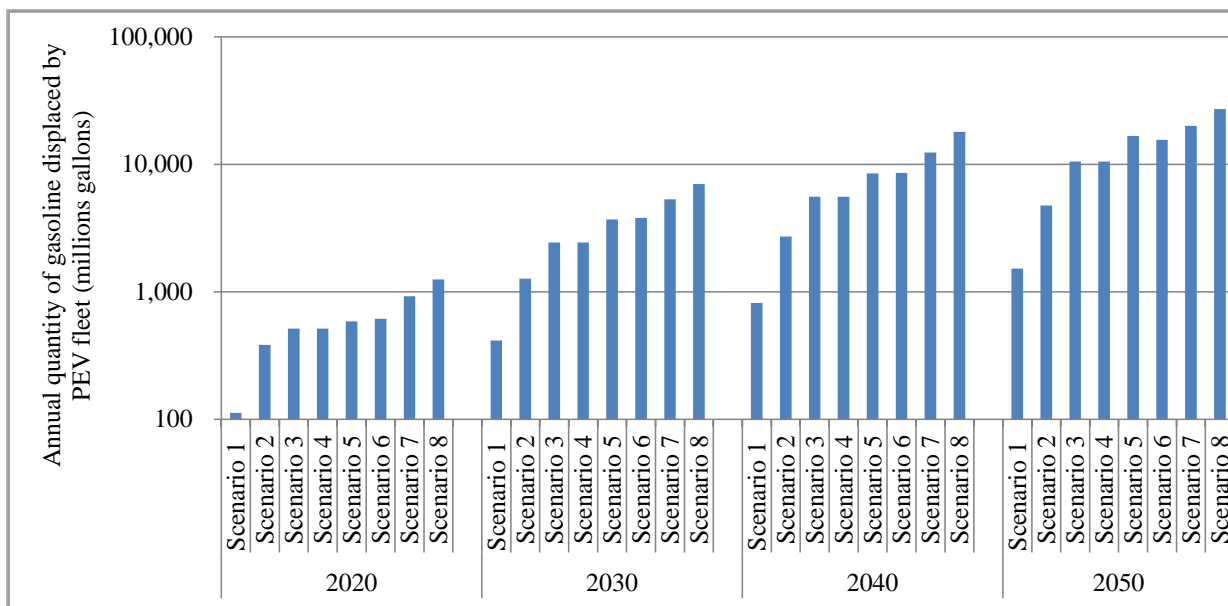


Figure 4: Decrease in annual volume of gasoline consumed by the U.S. light vehicle fleet due to PEVs, for each scenario

PEV purchasers

Based on National Household Travel Survey data, and assuming 70% of two-person households have two cars, there is a potential market for 26 million vehicles.

Figure 5 compares each scenario-year combination against the number of PEVs in the fleet (left-hand matrix), or BEVs in the fleet (right-hand matrix), categorized relative to the 26 million two-person, two-car households.

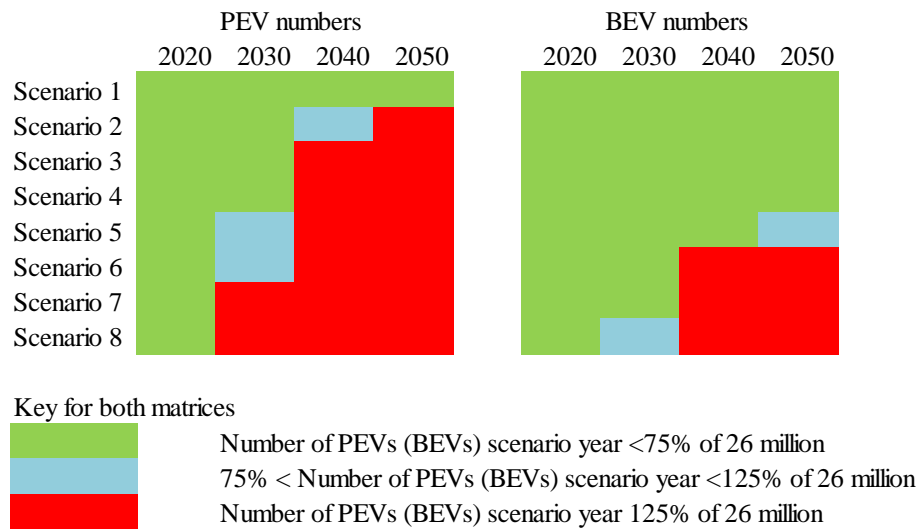


Figure 5: Matrix of which scenario-year combinations have PEV, or BEV, fleet deployment numbers within the number of two-person, two-or-more-car households

The figures show that if PEV ownership is restricted to this group of near-term customers, the PEV fleet figures for 2020, and BEV figures for 2030, could be met for all scenarios. To meet the PEV deployment numbers for Scenarios 7 and 8 in 2030, and Scenarios 3–8 in 2040, groups other than those in two-person households that owned a second car would need to purchase PEVs. Altering the purchasing criterion such that all second, third, and fourth (and so on) cars in a household could potentially be PEVs results in a finding that all of the PEVs (including BEVs) forecasted for all eight scenarios out to 2050 could be household “additional” vehicles.

EVSE analysis

Charging locations

The charging behavior for various locations by scenario and year is summarized in Figure 6.

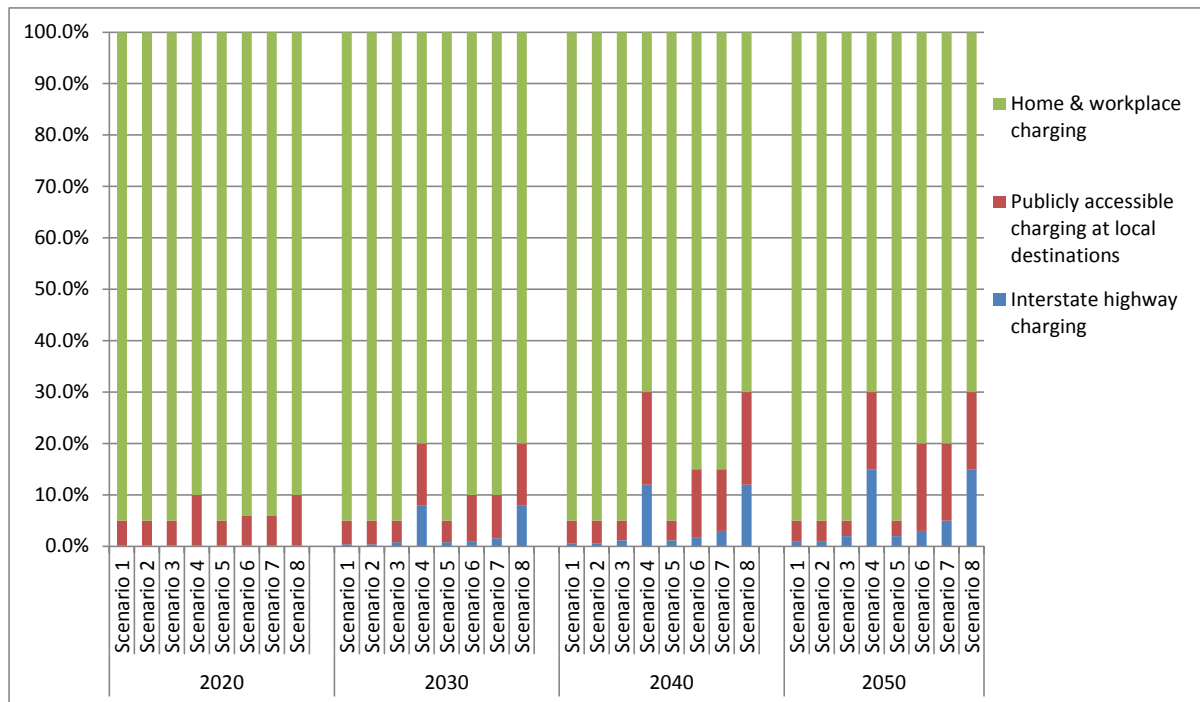


Figure 6: Charging location percentage by scenario and year

By 2020, it is assumed that 95% of charging occurs either at home or at the workplace for the majority of scenarios. By 2030, the scenarios span a much greater variation of charging options. The divergence of charging options is most evident in 2050. Scenario 1 presumes only very modest PEV uptakes, with 10 million PEVs in the fleet (of which approximately 2.4 million are BEVs), 95% of charging occurring at home and the workplace, and only 1% using Interstate highway charging points. On the other hand, Scenario 8 presumes enormous growth in electric vehicles, with 150 million PEVs in the fleet, of which 105 million are BEVs. Scenarios 4 and 8 investigate the implications of substantial Interstate highway charging. Even with these numbers, it is presumed that the majority (70%) of charging occurs at home and the workplace, because that is consistent with anticipated vehicle usage patterns and the anticipated extended range of vehicles.

Characteristics of charging events using publicly accessible charging stations

This assessment assumes that charging on or near the Interstate system will necessarily be DC Fast charging, while charging at local destinations uses Level 2 AC charging. Other characteristics and assumptions are given in Table 3.

Table 3: Assumptions regarding the characteristics of charging events at publicly accessible charging stations

	Publicly accessible charging not on or near the Interstate highway system	Publicly accessible charging on or near the Interstate highway system	Publicly accessible charging on or near the Interstate highway system
Type of charging station	Level 2	DC Fast charging	Tesla Super charging system
Average charge transferred per charging event	10 kWh (33-mile range)	20 kWh (66-mile range)	60 kWh (200-mile range (Teslamotors.com, 2013a))
Rate and duration of charge transfer	7.5 kW; 80 minutes	50 kW; 24 minutes	120 kW; 30 minutes
Average length of time vehicle is connected to the charging point	5 hours, reducing to 2.5 hours as etiquette becomes established	30–40 minutes	40 minutes
Average number of charging events per year per charging point	75	1,000	1,000

Number of charging events using publicly accessible charging stations and number of charge points required

When the total amount of charge provided to PEVs through publicly accessible Level 2 and DC Fast charging is divided by the average quantity of charge transferred for each charging event, the number of charging events per year results. This analysis results in the projected maximum average number of charging events that would occur for charging stations in the future, tabulated in Table 4, below.

Table 4: Average numbers of charging events for publicly accessible charging stations as a function of time

Battery charge type/ Year	2012	2020	2030	2040	2050
AC Level 2 publicly accessible charging station	75	500	1,000	1,500	1,500
DC Fast charger publicly accessible charging station	1,000	2,000	3,250	4,500	4,500

The minimum numbers of charging stations for the different scenario-year combinations can then be calculated, as presented in Figure 7 and Figure 8. For publicly accessible charging points for non-Interstate roads, this ranges from just over 10,000 for Scenario 1 in 2020 to about 5 million for Scenario 8 in 2050. For publicly accessible charging points for the Interstate, it ranges from below a thousand for all scenarios in 2020 to almost one million for Scenario 8 in 2050.

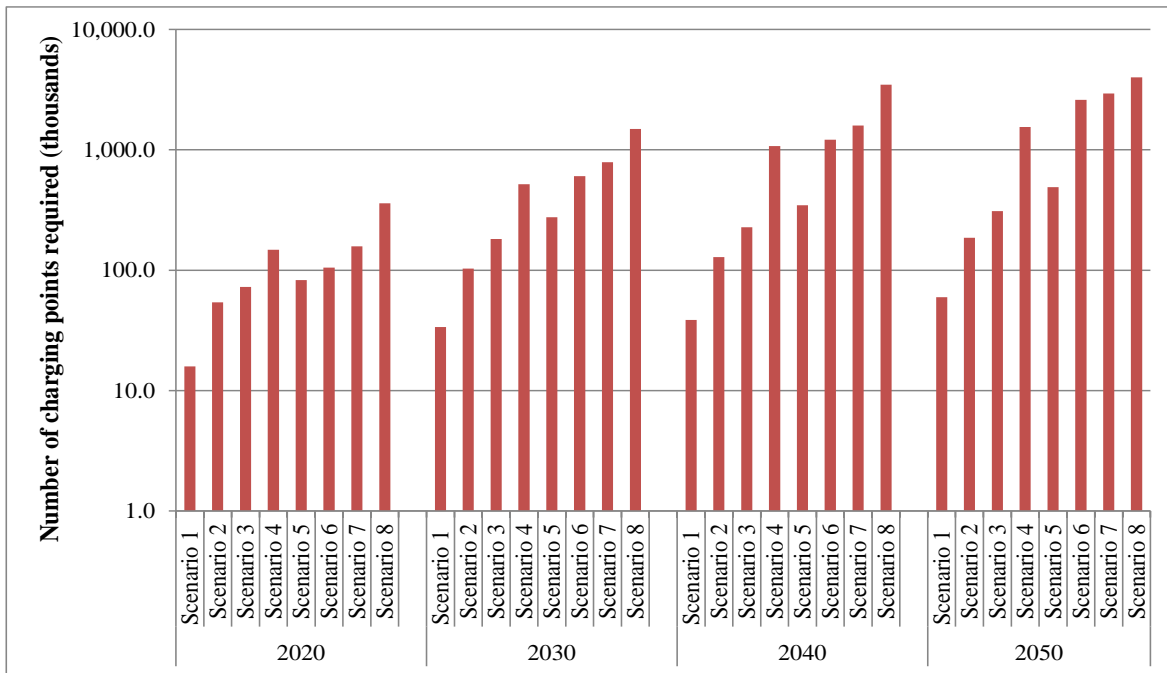


Figure 7: Number of publicly accessible charging points required by scenario for non-Interstate charging points

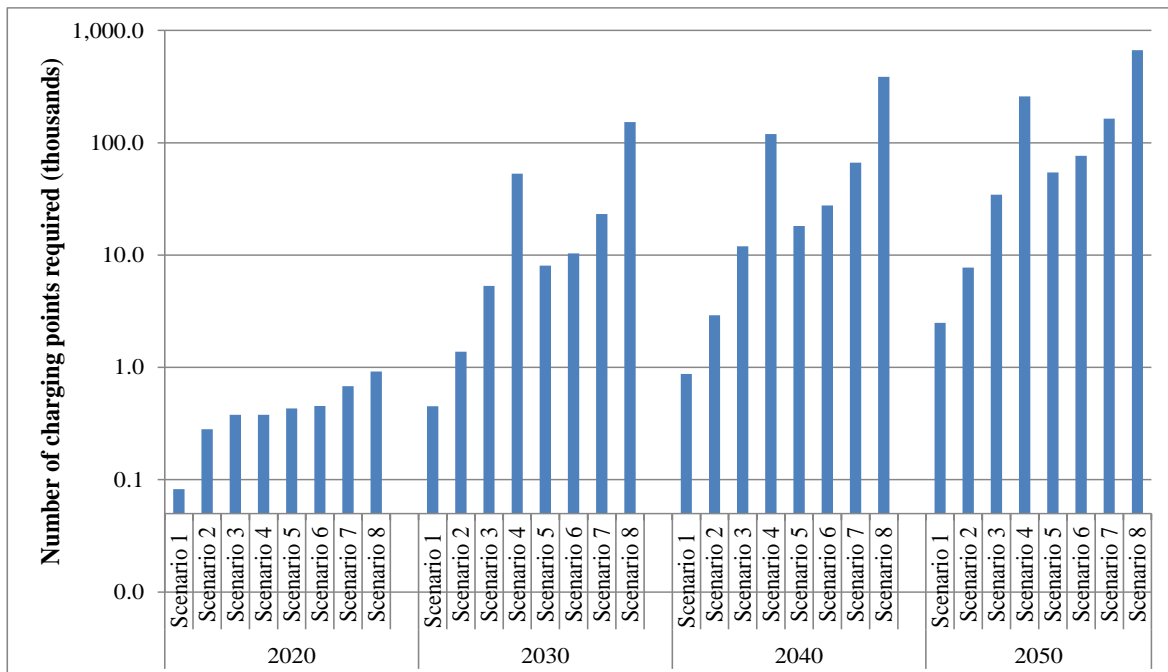


Figure 8: Number of publicly accessible charging points required by scenario for Interstate charging points

Power provision for charging stations

Shopping malls in the United States were analyzed as representative examples of local destinations for publicly accessible charging stations. The research calculated that there is likely already adequate capacity at shopping malls for PEV charging stations, for all scenarios out to 2030, and for the less aggressive deployment scenarios out to 2050.

For publicly accessible charging stations on or near the Interstate, rest areas were analyzed. There are an estimated 2,700 rest areas on the Interstate highway system in the United States, and when compared against the number of charging points required to meet the demand for Interstate highway charging, the number of potentially required charging points per rest area can be calculated. At the high end, slightly more than 1,000 charge points would be required per rest area under Scenario 8 in 2050, which does not seem feasible and indicates that if the Scenario 8 deployment levels have been reached by 2050, additional locations would be required beyond rest areas alone.

Cost and revenue analysis results

Costs for installing and using charging stations

A summary of charging station up-front cost estimates is given in Table 5. These costs are likely to decline in the future. In addition to the up-front hardware and installation costs, there will also be ongoing operations and maintenance costs.

Table 5: Summary of charging station cost estimates from various sources

Source	EVSE Type	Charger hardware cost low	Charger hardware cost high	Installation cost low	Installation cost high	Total cost low	Total cost high
(Plug In America, 2012a)	AC Level 1	\$100	\$500	\$100	\$500	\$200	\$1,000
(Plug In America, 2012a)	AC Level 2 Home	\$500	\$1,500	\$500	\$2,500	\$1,000	\$4,000
(Plug In America, 2012a)	AC Level 2 Commercial	\$2,000	\$6,500	\$3,000	\$5,000	\$5,000	\$11,500
(Plug In America, 2012a)	DC Fast	\$10,000	\$30,000	\$5,000	\$30,000	\$15,000	\$60,000
(U.S. Department of Energy, 2012c)	AC Level 2 Publicly accessible charging	\$1,000	\$3,000	\$2,000	\$8,000	\$3,000	\$11,000
(U.S. Department of Energy, 2012c)	DC Fast Publicly accessible charging	\$15,000	\$50,000	\$23,000	\$33,000	\$28,000	\$83,000
(ETEC, 2010)	AC Level 2 Publicly accessible charging	-	-	-	-	\$15,000	\$18,000
(ETEC, 2010)	DC Fast Publicly accessible charging	-	-	-	-	\$65,000	\$70,000
(Fuji Electric, 2012)	DC Publicly accessible Fast charging	\$25,000	\$60,000	\$20,000	\$20,000	-	-
(Inside EVs, 2013)	DC Publicly accessible Fast charging	\$16,500	-	-	-	-	-
(techcrunch.com, 2013)	Tesla Fast charging station	-	-	-	-	\$25,000	\$50,000

Revenue impacts associated with PEV deployment

CAFE standards being phased-in through model year 2025 will reduce per-mile consumption of motor fuels. In the absence of offsetting increases in total VMT, this phasing-in of CAFE

standards will lead to a reduction in motor fuel tax receipts. PEVs are one of the many strategies that manufacturers will use to meet the fleet-average CAFE targets. However, the extent to which PEVs will contribute to the overall CAFE targets is uncertain. This research presents the range of impacts that may result from deployment of PEVs in the context of the overall CAFE impact, based on the eight PEV deployment scenarios.

The Highway Trust Fund (HTF) is a transportation fund that receives money directly from a federal motor fuel tax, which is currently 18.4 cents per gallon on gasoline and which has been relatively constant since 1993. In addition to the federal motor fuel tax, individual states impose their own state motor fuel tax, as do some local jurisdictions, but this research considers only the federal tax implications of PEVs, based on the volume of gasoline displaced in the U.S. light vehicle fleet over-and-above the gasoline reductions projected from the light-duty GHG and CAFE standards.

The baseline HTF revenue from motor fuel tax is shown in Figure 9. This is based on the projected fuel consumption figures given in AEO 2013 and assumes the current rate of motor fuel tax.

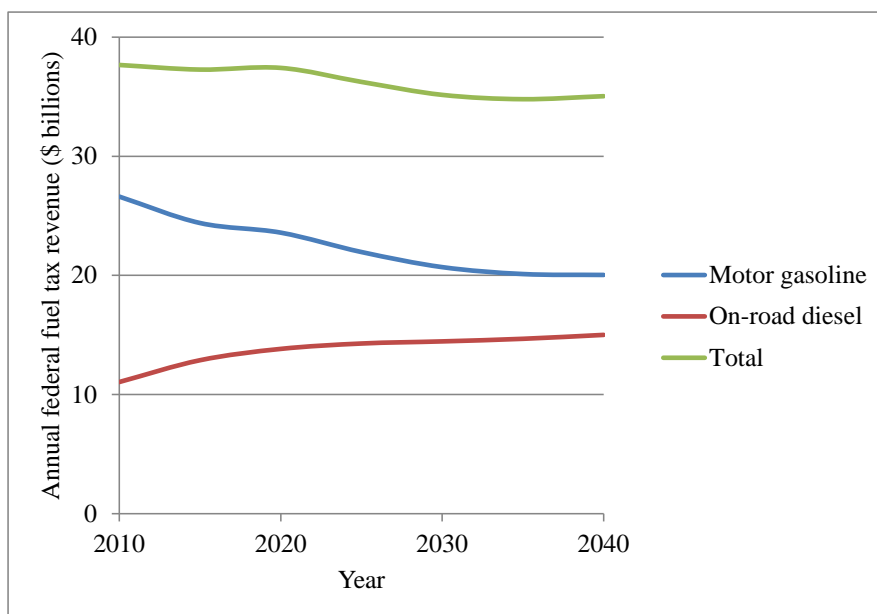


Figure 9: The federal motor fuel tax revenue from projected transportation fuel usage (EIA, 2013a)⁴

The AEO 2013 projections of gasoline consumption incorporate the projected reduction in gasoline use in future years caused by the increasing impact of the CAFE standards. However, if

⁴ The bases for this projected federal tax revenue are road transport fossil fuel usage as projected to 2040 in AEO 2013.

ICE fuel efficiency remained at the 2012 level (rather than improving, as is required by CAFE) then gasoline consumption would be higher than the AEO 2013 projection. The difference between the volume of gasoline calculated using the “2012 constant fuel efficiency” and the projected volume of gasoline in AEO 2013 allows us to estimate the reduction in HTF revenue caused by the CAFE program. This is presented in Figure 10, below.

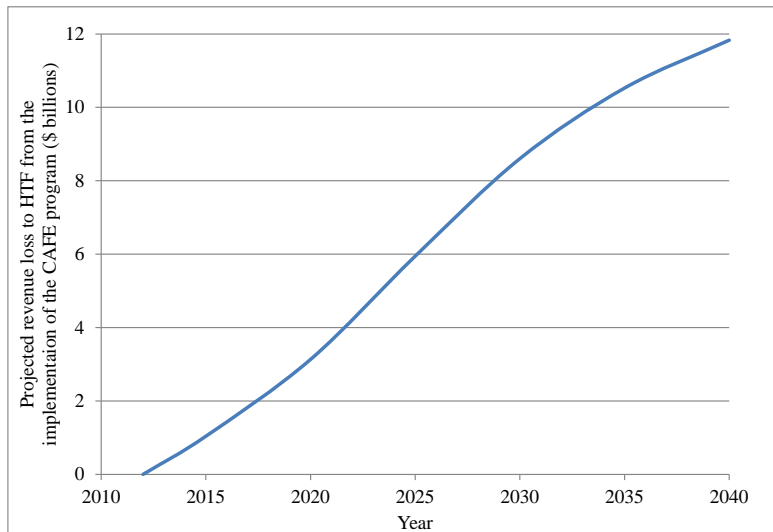


Figure 10: The reduction in HTF revenue relative to a constant 2012 level of ICE fuel efficiency

The overall impact of PEVs on HTF revenue cannot be considered separately from the impact of the CAFE standards. In this analysis, two cases are considered.

1. The first case presumes that CAFE standards taking effect out to 2025 will be met with only a minimal level of PEV deployment. After 2025, more fuel-efficient models will continue to be sold, and the light vehicle fleet will continue to become more efficient as older, inefficient vehicles are retired and replaced by new models that meet the 2025 efficiency requirements. In this case, the increasing deployment of PEVs, which occurs at an accelerated rate after 2025, leads to an additional reduction in gasoline sales beyond that resulting from CAFE standards. For this to be the case, it is also assumed there is no change in the average fuel economy of new ICE vehicles after 2025, even though the increased PEV sales would allow the introduction of less efficient vehicles without breaching the CAFE requirements.
2. The second case presumes that CAFE standards will be met using all the compliance credits resulting from PEV deployment. Consequently, up to 2025, increasing PEV sales help mitigate the need to improve ICE vehicle fuel efficiency. After 2025, the increasing deployment of PEVs causes ICE vehicle average fuel economy to decrease (because the increased PEV sales enable less efficient vehicles to enter the fleet without CAFE requirements being breached).

For the first case, the baseline deployment scenario described in AEO 2013 predicts a reduction in gasoline sales due to CAFE standards, and the incremental deployment of PEVs for the scenarios presented are **additional** fuel efficiency improvements, beyond those due to CAFE. This additional improvement leads to further reductions in gasoline sales. **These are the reductions calculated in this report.**

For the second case, the reduction in gasoline sales caused by the deployment of PEVs is offset by an increase in gasoline sales caused by ICE vehicles becoming less fuel-efficient than they otherwise would under CAFE requirements. **For this case, the net change in gasoline sales is zero.**

Actual gasoline sales impacts will likely fall somewhere between the two extremes described by the two cases above, although the precise number of CAFE credits that will be generated by PEVs under the different deployment scenarios is unknown. **Therefore, the impact of PEV deployment on HTF revenue is a possible range from zero to the maximum values calculated and reported herein.**

The maximum revenue impacts for all eight scenarios are tabulated in Table 6, and presented graphically for three sets of scenarios (Scenario 1, Scenarios 5 & 6, and Scenario 8, which provide relatively even growth steps in PEV deployment numbers) in Table 6.

In Figure 11, solid lines are the revenue impacts based on 13 kWh displacing a gallon of fuel, and upper and lower broken lines are a sensitivity analysis based on equivalency factors of 9 kWh and 17 kWh.

Table 6: Maximum reduction in annual federal motor fuel tax revenue caused by electric PEV travel by scenario (billion dollars)

Scenario	Scenario prediction	2010	2020	2030	2040	2050
Sc 1	Baseline	0.002	0.023	0.104	0.186	0.317
Sc 2	Modest additional growth	0.002	0.079	0.312	0.603	0.966
Sc 3	Larger additional growth	0.002	0.107	0.611	1.269	2.193
Sc 4	Larger growth & Interstate highway charging	0.002	0.107	0.611	1.269	2.193
Sc 5	Based on EPRI medium growth	0.002	0.122	0.927	1.932	3.474
Sc 6	Based on EPRI medium growth and extended range	0.002	0.128	0.951	1.954	3.250
Sc 7	Larger growth than Sc 6	0.002	0.192	1.332	2.820	4.170
Sc 8	Based on EPRI high growth, extended range & highway charging	0.002	0.260	1.755	4.108	5.657

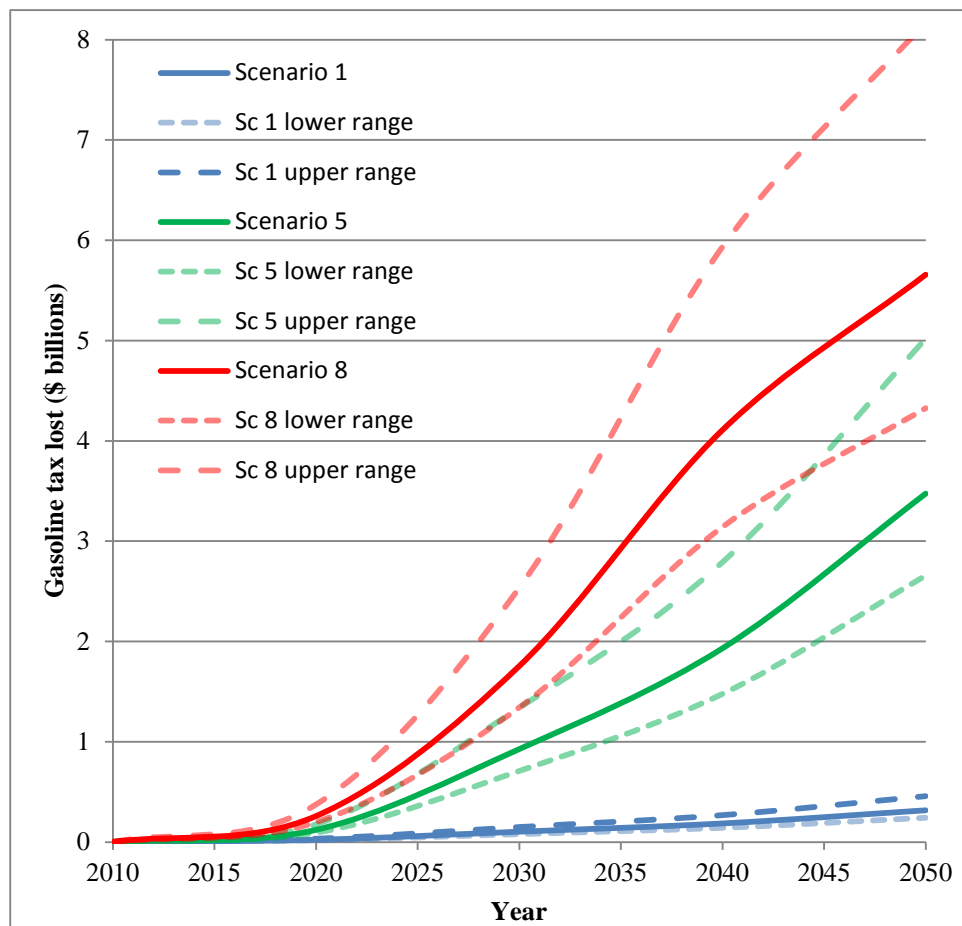


Figure 11: Maximum reduction in annual federal motor fuel tax revenue caused by electric PEV travel by scenario

The largest reduction—the reduction due to Scenario 8 in 2050—represents a reduction of approximately 16% relative to the reference scenario. However as noted above, the actual impact of increased PEV deployment may lead to some reduction in federal motor fuel tax revenue by a figure within the range of zero (if all the PEV deployment is used to meet the CAFE standards) to the maximum figures presented in Table 6. Even at the highest deployment levels, the motor fuel tax impacts of PEVs are a relatively small fraction of the overall impact of the CAFE program.

FHWA may wish to consider alternative revenue schemes to mitigate the impact of PEVs. In addition to addressing possible reduced revenues, this would also allow FHWA to respond to possible concerns about the perceived lack of equity of some transportation system users not “paying their fair share.” Options for addressing the revenue losses attributable to PEVs include: (A) Increase the motor fuels tax; (B) Levy a PEV excise tax; or (C) Levy a mileage tax.

POTENTIAL PATHWAYS FOR FHWA, STATE DOT AND OTHER TRANSPORTATION AGENCY ACTION

Drawing on the analysis of the eight scenarios, the research team proposes three potential pathways for FHWA, State DOT, and other transportation agency action. The pathways suggested are additive, in that the second and third response levels are additional to the first level. The minimum response level we name **Market Response**. This pathway represents catching up to the PEV market activity so that transportation agencies do not become an impediment to the advancement of the technologies. The second pathway we call **Market Support**. This pathway involves a more active effort by FHWA and state and local agencies to deliberately keep pace with the deployment of vehicles and charging stations. The most aggressive of the pathways we name **Market Acceleration**. This set of activities goes beyond supporting the private sector and proactively promotes the deployment of PEVs in the United States. The pathways and accompanying actions are summarized in Table 7, below.

Table 7: Summary of suggested pathways for FHWA, State DOTs, and Other Transportation Agencies

Source	Market Response	Market Support	Market Acceleration
Policy, regulations, and statutory issues	<p>Support the renewal of the Federal Tax Credit for PEVs.</p> <p>Support local state tax incentives for PEVs.</p> <p>Support the adoption of a single permit type for home charging stations at the state building code office.</p>	<p>Support one plug standard.</p> <p>Support utilities in the development and implementation of time of use pricing, programmed off-peak charging and the balancing of intermittent renewables with smart metering.</p> <p>Support the development of state Renewable Portfolio Standards.</p>	<p>Support increased performance in CAFE standards.</p> <p>Support a national Low Carbon Fuel Standard.</p> <p>Support increased performance in, and expansion of, zero emission vehicle rules.</p> <p>Support third-party right to sell electricity.</p>
EVSE in different travel markets	<p>Promote charging stations at opportunity sites.</p>	<p>Develop charging stations in key intercity corridors.</p>	<p>Develop an expanded intercity charging stations network.</p>
Highway design standards and infrastructure	<p>Encourage PEV use of HOV lanes.</p>	<p>Adopt standards for charger parking space dimensions.</p>	<p>Support research into the integration of charging technology and highway infrastructure (e.g., wireless charging).</p>

Source	Market Response	Market Support	Market Acceleration
Safety, emergency services, and incident response	<p>Promote the distribution of new national guidance that provides an online safety training course for first responders.</p> <p>Promote the distribution of information to second responders such as tow truck operators.</p>	<p>Coordinate with NHTSA which chairs the Global Technical Regulations (GTR) international effort to address occupant safety from high-voltage electric shock and safety protocols for electrical components.</p>	<p>Continue to coordinate with NHTSA on safety and emergency response issues.</p>
Signage, information networks, and online mapping	<p>Provide better signage for motorists that differentiates between charging types.</p> <p>Provide way-finding signage off the ROW and all the way to the charging station.</p> <p>Parking space signage standardization.</p>	<p>Promote the use of smartphone apps (e.g., http://www.plugshare.com/ and Alternative Fueling Station Locator).</p> <p>“Next Charge in X Miles” signage.</p>	<p>Continued promotion of smartphone apps and other trip planning and charger way finding.</p>
Revenue impacts and potential costs	<p>No action suggested.</p>	<p>Consider state-level registration fees.</p> <p>Consider state efforts on VMT tax such as Oregon’s pilot for any vehicle.</p>	<p>Consider federal-level PEV excise tax.</p> <p>Consider a Road User Fee.</p>

Source	Market Response	Market Support	Market Acceleration
<p>Administrative activity and additional research</p>	<p>Switch a portion of FHWA’s fleet to PEVs.</p> <p>Lead the coordination of Federal agencies, EPRI, and vertically integrated utilities.</p> <p>Provide technical assistance to state-level programs and respond to their specific needs.</p> <p>Map the actual locations of retail-dense interchanges that correlate to approximately 25–60-mile intervals on intercity corridors.</p> <p>Track locations of charging stations to determine adequacy of corridor charging.</p> <p>Research future regional deployment variations</p>	<p>Distribute and promote the C2ES Plug-In Electric Vehicle Action Tool to state DOTs and local agencies.</p> <p>Map the actual locations of retail dense interchanges that correlate to approximately 25–60-mile intervals on a broader network that links all intercity corridors with PEV and charging station density.</p> <p>Collaborate with other government agencies on public service advertisements to communicate the importance of PEVs on the overall transportation system.</p>	<p>Expanded administrative and research activities described in the preceding pathways.</p>

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Glossary of abbreviations

23 USC 111	Title 23 of the U.S. Code (Highways) Sub-section 111
AAA	The American Automobile Association Inc.
AC	Alternating current
ADA	Americans with Disabilities Act
AEO	Annual Energy Outlook
ARRA	American Recovery and Reinvestment Act
BEV	Battery electric vehicle
CAFE	Corporate average fuel economy
CD	Charge depleting mode, i.e., the operating mode of a REEV or PHEV when running on battery
CFS	Clean Fuel Standard
CHAdcMO	Charge do Move, Trade name for a fast charging protocol developed by the Tokyo Electric Company, Nissan, Mitsubishi, and Fuji Heavy Industries
CMAQ	Congestion Mitigation and Air Quality
COG	Council of Governments
CO₂e	Carbon dioxide equivalent
CS	Charge sustaining mode, i.e. the operating mode of a REEV or PHEV when running on gasoline
CW	Curb weight
DC	Direct current
DOE	Department of Energy
DOT	Department of Transportation
EIA	Energy Information Administration
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EV	Electric vehicle
EVSE	Electric vehicle supply equipment
FHWA	Federal Highway Administration
GFCI	Ground fault circuit interrupters
GHG	Greenhouse gas
GVWR	Gross vehicle weight rating
HEV	Hybrid electric vehicle

HOV	High occupancy vehicle (vehicle with more than one occupant, often defined by a sign at the entrance to an HOV lane)
HTF	Highway Trust Fund
ICE	Internal combustion engine
JRC	Joint Research Centre (of the European Commission)
LCFS	Low Carbon Fuel Standard
Li-ion, Li-air	Lithium-ion, lithium-air, etc. (types of rechargeable batteries)
MAP-21	Moving Ahead for Progress in the 21st Century
MSA	Metropolitan statistical area
MUTCD	Manual on Uniform Traffic Control Devices
NHTS	National Household Travel Survey
NHTSA	The National Highway Traffic Safety Administration
PEV	Plug-in electric vehicle (encompasses BEV, PHEV, and REEV)
PHEV	Plug-in hybrid electric vehicle
PUC	The Public Utility Commission
REC	Renewable Energy Certificate
REEV	Range-extended electric vehicle
ROW	Right of Way
RPS	Renewable Portfolio Standards
SAE	SAE International, formerly Society of Automotive Engineers, a U.S. professional association and standards organization
STP	Surface Transportation Program
USABC	U.S. Advanced Battery Consortium
VMT	Vehicle miles traveled
ZEV	Zero emissions vehicle

1 INTRODUCTION

Significant economic, national security, and environmental costs are associated with the petroleum-based fuels currently used in our transportation system. For this and other reasons, vehicle manufacturers and the traveling public are increasingly investing in plug-in hybrid and other electric vehicle (EV)⁵ technologies. The increased use of these technologies promises to yield multiple benefits, including lower localized and regional on-road emissions and a reduced reliance on foreign sources of oil. The federal government, states, and localities in the United States are beginning to build the necessary infrastructure and enact incentives to support the use of these vehicles. The Obama Administration supports the deployment of plug-in electric vehicles (PEVs) as part of its broad alternative energy policy.

Understanding the impacts of a significant increase in the use of PEVs is important for the Federal Highway Administration (FHWA) and other U.S. Department of Transportation (U.S. DOT) modal administrations, as such use likely affects their mission and programs. Existing highway infrastructure and funding is designed around a gasoline- and diesel-powered vehicle fleet. A substantial increase in the number of PEVs in use will create a significant difference in fueling practices and thus require new charging infrastructure. In addition, expanded PEV use may have other implications for highway finance, safety approaches, and operations. Given the potential benefits described above, FHWA must evaluate whether existing infrastructure, programs, and practices pose impediments or could be modified to better facilitate and encourage the use of PEVs.

In September of 2012, FHWA initiated the *Feasibility and Implications of EV Deployment and Infrastructure Development* project (“the FHWA EV project”) to help evaluate the prospects and expectations for short- and long-term deployment of PEVs. The FHWA EV project analyzed the potential deployment of PEVs in the United States and their potential impact on the mission of FHWA, including financial implications for available highway revenues. The project seeks to help transportation agencies to understand whether and how transportation policies, programs, infrastructure, services, funding models, and administrative activities may have to change as more PEVs are deployed on highways, roads, and streets—whether by simply responding to the increased vehicles, more actively supporting them, or proactively helping to accelerate their deployment.

⁵ Unless otherwise specified, throughout this document the term Electric Vehicles (EVs) refers to the spectrum of vehicles that are powered at least in part by plugging into the electric power grid. EV configurations include pure battery electric vehicles (BEVs), plug-in electric vehicles (PEVs), plug-in hybrid electric vehicles (PHEVs), and range extended electric vehicles (REEVs). The terms EV and PEV are generally used interchangeably.

The FHWA EV project consisted of the following main research elements:

- A **literature review**, which gathered information from academic journals and other publicly available sources related to PEVs and their deployment, and was updated several times over the course of the project.
- A series of **expert interviews**, which collected information from state Departments of Transportation (DOTs) and other government agencies, electric vehicle manufacturers, Electric Vehicle Supply Equipment (EVSE) manufacturers and operators, industry stakeholders and non-governmental organizations (NGOs), utilities, academia, and research institutions.
- A series of **federal agency staff interviews**, which collected information on federal agency research and development initiatives as well as pilot programs and deployment efforts being supported by the federal government.
- An **EV Forum**, which convened over 50 practitioners in the energy, highway, and vehicle sectors to solicit expert input for the technical aspects of the project.
- The development of eight credible PEV **market penetration scenarios**, ranging from conservative to very ambitious, and reflecting potential usage patterns for the years 2020, 2030, 2040, and 2050.
- Quantitative and qualitative **analysis** of the PEV market penetration scenarios.
- Development of four **case studies** of PEV deployment (see Appendix F):
 - California Bay Area and Monterey Bay Area.
 - North Carolina Greater Charlotte Region.
 - Oregon I-5 Metro Areas.
 - Texas Greater Houston Area.
- Development of this **Final Report**, including consideration of the following:
 - Policy, regulatory, and statutory issues.
 - EVSE in different travel markets.
 - Highway design standards and infrastructure.
 - Safety, emergency services, and incident response.
 - Signage, information networks, and online mapping.
 - Revenue impacts and potential costs.
 - Administrative activity.
- **Outreach** to key stakeholders at relevant conferences and events.

This Final Report summarizes the information gathered during the various foundational research activities, describes the development of the eight market penetration scenarios, presents the methodology used to undertake the analysis, summarizes the findings of the analysis, and presents conclusions covering a range of possible “pathways” for FHWA and partner action, including possible additional research for consideration.

2 FOUNDATIONAL RESEARCH

The findings from the foundational research conducted during the initial phases of the FHWA EV project are presented in this chapter.

2.1 VEHICLES

2.1.1 Types of PEV

This research focuses on vehicles fitted with batteries that provide energy for motive power, and that can be recharged via an external power source. Such vehicles are known collectively as “plug-in electric vehicles” (PEVs). These vehicles use grid electricity as an alternative to fossil fuels for providing motive power. Hybrid electric vehicles (HEVs) that cannot be re-charged by an off-vehicle electric energy source are not considered PEVs, and are excluded from this research.

PEVs can be classified into three general groups:

- battery electric vehicles (BEVs).
- plug-in hybrid electric vehicles (PHEVs).
- range-extended hybrid electric vehicles (REEVs).

While BEVs are powered entirely by on-board batteries, PHEVs and REEVs have both electric motors and an internal combustion engine (ICE), so they are forms of hybrid vehicles. The drivetrains of PHEVs are typically derived from those of regular HEVs (such as the drivetrain of the Mercedes ML450 Plug-in). PHEVs generally favor battery power and engage the ICE as often as needed based on driving conditions. REEVs typically operate solely under battery power, and use the ICE only to extend the vehicle range once the battery is depleted.

PHEVs and REEVs can typically operate in two modes: one relying only electricity from the battery, known as charge depleting (CD) mode; and one in which battery charge is held roughly constant and the vehicle is powered by the ICE, known as charge sustaining (CS) mode. In a hybrid drivetrain, the ICE is either mechanically connected to the wheels (parallel hybrid or power-split hybrid) or used only for the generation of electricity for the electric traction motors or the battery (serial hybrid). A schematic of the power flows for the different vehicle types is presented in Figure 12. The schematic in Figure 12 demonstrates the flow of power for four different engine types;

1. **Parallel Hybrid Powerflow:** internal combustion engine and battery power flowing through the clutch and electric motor to the transmission then wheels. Examples: the New Range Rover; Mercedes ML450.

2. **Serial Hybrid Powerflow:** internal combustion engine power flowing to the electric generator and then straight to the electric motor or going to the electric motor via the battery before flowing to the transmission then wheels. Example: BMW i3.
3. **Battery Electric Vehicle Powerflow:** power flows in a straightforward line from battery to electric motor, then transmission then wheels. Examples: Nissan LEAF; virtually all BEVs.
4. **The Conventional Internal Combustion Engine:** power flows from the internal combustion engine to the clutch, transmission, and finally to the wheels.

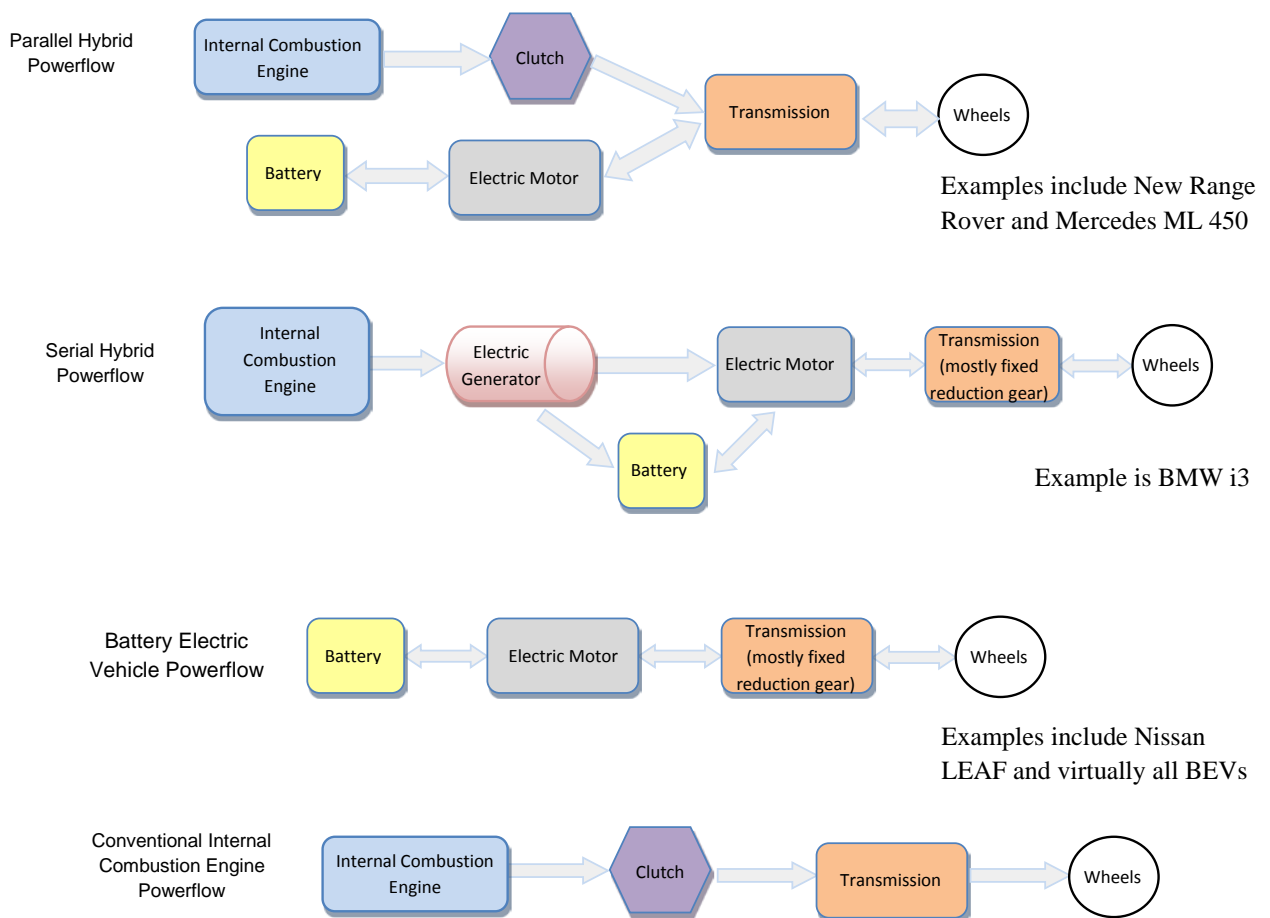


Figure 12: Schematic of the power flows for different vehicle types

The Toyota Prius Plug-in and the Chevrolet Volt both feature power-split drivetrain layouts, which enable a combination of serial and parallel hybrid power transmission, although the Chevrolet Volt is mostly operated as a serial hybrid when in charge depletion mode (Ma, 2011).

Consequently, neither fits conveniently into the pure parallel or serial hybrid power flows shown in Figure 12. PHEVs typically features a parallel/power split layout to provide a direct mechanical connection from ICE to wheels, for greater fuel efficiency. REEVs tend to be associated with the mechanically simpler serial hybrid powertrain layout to provide extra range where needed.

Because BEVs are powered only by on-board batteries, they are much more reliant on the availability of charging infrastructure than PHEVs or REEVs.

2.1.2 PEV vehicle market

Many of the major car manufacturers including GM, Ford, Toyota, Nissan, Mitsubishi, Daimler, BMW, and Volkswagen have PEVs on the market or have announced they will introduce PEVs on the market within the next year. Other PEVs on the market include those made by specialist manufacturers (e.g., Tesla). The current market for PEVs is mostly concentrated on passenger cars. It is forecasted that globally, more than 80% of the vehicle battery market in 2015 will be for light vehicles such as passenger cars and light trucks, rather than heavy trucks (Roland Berger, 2011) (CE Delft, 2011b). Table 8 shows the various vehicle classes in the United States, along with their current compatibility with respect to the PEV power-train groups, as indicated in the key below the table. The basis for “compatibility” is whether the PEV type can provide enough power and range for typical applications at potentially reasonable cost.

Table 8: Different vehicle classes in the U.S. and their compatibility with different PEV power-train groups

Vehicle class	Weight range*	PHEV	REEV	BEV
Passenger car: Mini & Light	1,500 < CW < 2,499 lbs	Orange	Orange	Green
Passenger car: Compact & Medium	2,500 < CW < 3,500 lbs	Green	Orange	Green
Passenger car: Heavy	CW > 3,500 lbs	Green	Orange	Green
Class 1 Truck: Light truck**	GVWR 6,000 lbs & less	Orange	Red	Orange
Class 2 Truck: Light truck**	6,000 < GVWR 10,000 lbs	Orange	Red	Orange
Class 3, 4 & 5 Truck: Medium truck	10,000 < GVWR 19,500 lbs	Red	Red	Orange
Class 6–8 Truck: Heavy truck	GVWR > 19,500 lbs	Orange	Red	Red

*While the above classification is in terms of either curb weight (CW) for passenger cars, or gross vehicle weight rating (GVWR) for trucks, cars can be categorized in terms of their body type, e.g. luxury, sports, convertibles etc.

**Class 1 and 2 trucks include pickup trucks, sports utility vehicles (SUV), mini vans, and cargo vans.

Note: The color coding is based on the research team’s familiarity of the PEVs available, and the key used is:

Green: This type of powertrain is well-suited for this vehicle class.	Green
Orange: This type of powertrain has been demonstrated for this vehicle class, but very few models are available.	Orange
Red: This type of powertrain is virtually unknown for this vehicle class.	Red

2.1.3 PEV technical characteristics

2.1.3.1 Battery characteristics

Batteries significantly affect the costs, performance, and development of electric vehicles. Relevant battery features include energy storage capacity (kWh), peak output (kW), calendar life, cycle life, thermal management, costs, and recharge time (EC JRC, 2009).

Battery types and performance: There are various battery technologies available for use in PEVs. While nickel metal hydride (NiMH) batteries are used in HEVs such as the Toyota Prius, current plug-in vehicles almost exclusively use lithium-ion (Li-ion) type battery chemistries. One of the principal reasons for using Li-ion batteries is the high energy density levels achievable from these chemistries (as illustrated in Figure 13).

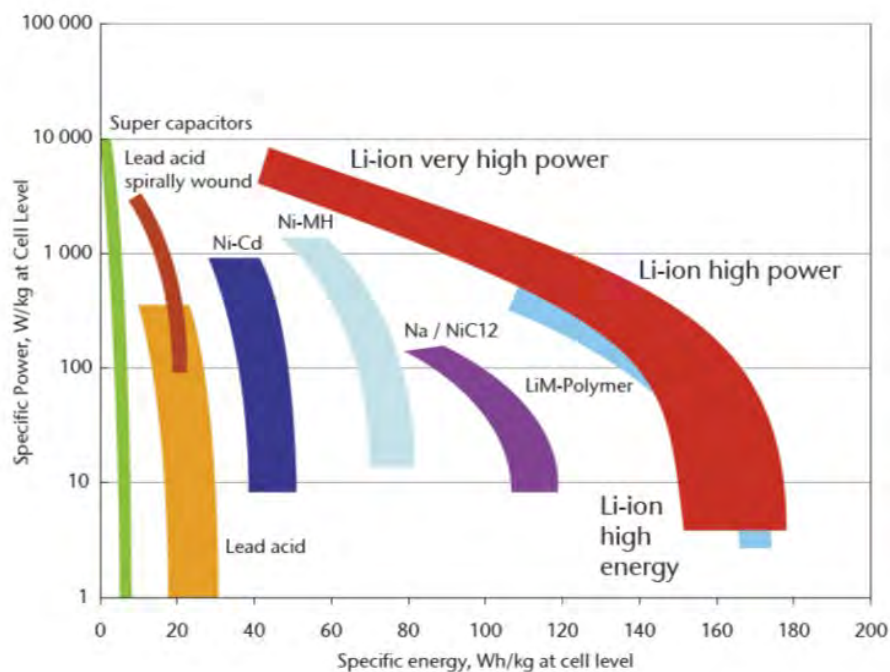


Figure 13: Specific power and energy for different battery chemistries

Storage capacity of batteries: Figure 13 denotes the specific power and energy for different battery chemistries. The diagram shows that the energy density of Li-ion batteries is currently in the range 0.12–0.15 kWh/kg (for comparison, the energy density of gasoline is approximately 13kWh/kg, although ICEs are approximately three times less efficient at converting potential energy into motion). It is generally expected that incremental improvements in battery technology will lead to densities approaching 0.20 kWh/kg (International Business Times, 2011). Alternatively, there could be a step change due to radical advances in technology. For example, the new experimental Envia Li-ion battery has a storage capacity of 0.4 kWh/kg (Scientific

American, 2012b). If completely new battery systems like the lithium-air (Li-air) battery are commercialized, energy density could improve from current levels by a factor of 10, to approximately 1.25 kWh/kg (Scientific American, 2012a). Research papers indicate that there are a number of technical challenges to be overcome, and success cannot be guaranteed. However, even if the research is successful and high energy density batteries can be made, ultimately two key uncertainties remain:

- The date when they become widely available, which is probably at least 10 years away.
- The cost of production.

Battery aging: The “as new” storage capacity of a battery degrades with use, which is known as battery wear. In the literature, a battery’s end of life is typically understood as the point at which capacity and power are less than 80% of their initial values (Element Energy Limited, 2012). The U.S. Advanced Battery Consortium (USABC), which supports vehicle battery research and development in the United States, has set the goal for minimum PEV battery life at 10 calendar years and 1,000 full cycles⁶ for BEV batteries and 5,000 full cycles for PHEV batteries (CE Delft, 2011a). However, it is uncertain to what extent such targets have already been met or exceeded in practice. Battery life significantly depends on climatic conditions (extreme high or low temperatures reduce battery life) and other variables, including terrain (hills vs. flat surfaces), as well as rates and levels of charging and discharging⁷, and the battery’s cathode chemistry (US Department of Energy, 2012a). Fast charging may also lead to greater battery wear (Battery University, 2012). During the expert interviews conducted for this study, one of the experts described the difficulties associated with developing and testing PEV batteries; batteries are not microchips and do not have the same life cycle as consumer electronics. Accelerated life testing, especially for a battery with an estimated 10-year battery life, is difficult to perform.

The experts also highlighted the technologies that are currently used in PEVs to extend battery life, including battery temperature management systems and the use of only a limited window of a battery’s full capacity. GM, Tesla, and Ford use liquid-cooling systems for their PEV batteries, while the Nissan LEAF, for example, uses air cooling. Liquid cooling can remove heat from cells more quickly and ensures that there is little variation in temperature between cells (MIT Technology Review, 2010). Leaving a larger margin in how low a battery can be discharged and in how fully it can be charged is another technology design used to extend battery life. For example, the REEV Chevrolet Volt uses only 50% of its battery’s capacity (Wood et al, 2011), while pure BEVs typically use approximately 80% (Element Energy Limited, 2012).

⁶ "Full cycle" is used to express the discharging of a battery such that no more than 20% of its charge remains, i.e. it involves using at least 80% of the fully charged battery’s available power. For lithium ion batteries, full discharge can mean discharging until the battery’s voltage is 3.00 volts per cell, at which point only approximately 5% of its energy remains.

⁷ Battery life is dependent on thermal history because prolonged rapid charging or discharging leads to a build-up of internal temperature which shortens the lifetime of the battery, by an amount which also depends on the battery chemistry (cobalt or manganese oxide, phosphate or titanate cathodes).

The 2013 Nissan LEAF's warranty in the United States covers battery repair or replacement in cases in which the battery capacity falls by more than 30% within five years or 60,000 miles (Autotrader.com, 2013). This policy suggests that these levels of battery capacity degradation represent a minimum level of typical performance, even under unfavorable climatic and operational conditions. A recent article estimates that PEV battery life could last up to 20 years under favorable conditions (Design News, 2013).

Battery costs: A variety of figures were quoted during the foundational research as current market prices for battery cost. Typically, figures are given in units of \$/kWh, although usually it is not specified which costs are included in the estimate. According to Element Energy (2012) the 2011 cost of a complete 22kWh BEV battery pack inclusive of housing, cooling, and battery management system is about \$800/kWh—about double the cost of the cell alone. Generally, the larger the battery pack, the lower the cost per kWh. For example, Element Energy (2012) estimates that a 12 kWh PHEV pack, with 60kW peak power output, would cost more than \$1,300/kWh.

Battery costs have fallen significantly in recent years, and various projections anticipate battery costs dropping significantly further over the coming years. Table 9 provides an overview of estimates of past, present, and future battery costs.

Table 9: Forecasts of the price of EV batteries

Research entity	Baseline cost	Baseline year	Change in cost relative to baseline	Date for change in cost relative to baseline	Comments
Boston Consulting Group (BCG Focus, 2010)	\$1,000 to \$1,200	2009	-60% to -65%	2020	The cost target of \$250/kWh is unlikely to be achieved for either cells or battery packs by 2020
Centre for Automotive Research (Center for Automotive Research, 2011b)			-\$300 /kWh	2025	
International Energy Agency (IEA, 2011)	\$500 to \$800	2011	-\$300 to -\$400/kWh, i.e., -50%	2020 or earlier	Identified as critical aspect for wider deployment of EV
Bloomberg New Energy Finance	\$1000+/kWh \$800/kWh \$689/kWh	2009 Q1 2011 Q1 2012	-\$150/kWh	2030	Prediction from EV Battery price index analysis
CE Delft (CE Delft, 2011b)	\$770/kWh	2012	\$415/kWh -\$250/kWh	2020 2030	Mean of Li-Mn-spinel & Li-Si

(Element Energy Limited, 2012) contains one of the most comprehensive assessments of battery costs. Its baseline projection for a BEV pack of approximately 20 kWh is given in Table 10.

Table 10: Projections of battery costs and energy density (from a study for UK Committee on Climate Change)

Timeframe	Change in cost rel. to baseline	Cost \$/kWh	Energy density kg/kWh
2011 (baseline)		~\$800 /kWh	11.5 kg/kWh
2020	-50%	~\$400 /kWh	8 kg/kWh
2030	-70%	~\$240 /kWh	6 kg/kWh

Based on the figures commonly quoted in the literature, it appears reasonable to expect that a battery of approximately 20kWh would have manufacturing costs somewhere between \$10,000 and \$20,000 in 2011–2012. During the panel member interviews, a U.S. Department of Energy (DOE) representative noted that at present, automobile manufacturers are losing money on battery pack manufacturing. One recent event challenges this timeline. Tesla Motors, in July 2014, announced the planned development of a battery “gigafactory” in the United States. According to Tesla, the plant’s scale and improved manufacturing technology could reduce production costs by 30%, and bring battery pack costs to \$200 per kWh, a cost that would allow packs to compete on price without subsidies (The Economist, 2014).

The importance of battery development and cost reduction strategies is acknowledged by national governments. For example, as part of the American Recovery and Reinvestment Act (ARRA), \$2.4 billion of funding was granted to support 48 advanced battery and electric drive projects (US Department of Energy, 2009).

Reductions in battery prices give manufacturers the option of reducing purchase prices or, for a given price, increasing vehicle driving range by increasing pack sizes. The expert interviews indicated that currently, most vehicle manufacturers have decided it is more important to use the gains in battery technology to reduce the cost of the vehicle, rather than to extend the range. The vehicle manufacturers believe that a less costly car is more important to consumers today than extended battery capacity and driving range. This approach also allows for more cargo capacity than if the same space were used for additional batteries. Thus, manufacturers will likely sell more cars if the price of the vehicle is reduced.

2.1.3.2 Other vehicle characteristics

Weight: On a like-for-like basis, BEVs are approximately 20% heavier than their ICE equivalents. (For example, a Ford Focus Electric weighs approximately 23% or 700 lbs more than an ICE Ford Focus; Mitsubishi's i-MiEV is approximately 21% heavier than the ICE Mitsubishi I). PHEVs are also heavier, though by a smaller percentage, than their HEV equivalents.

Speed and acceleration: In terms of driving performance, PEVs are not expected to differ significantly from today's cars, although they do have better torque at low speeds, leading to potentially higher rates of acceleration. Additionally, the maximum speed is usually lower for electric vehicles (for example, the Ford Focus Electric has a maximum speed of 84 mph, whereas the 1.6-liter ICE equivalents all have maximum speeds of 116 mph or greater).

Range: The energy consumption of most small and compact BEVs on the market tends to be 10–30 kWh/100km, depending on driving and weather conditions (TU Vienna, 2012). Because battery pack sizes are approximately 20 kWh, driving ranges in practice are 40–120 miles. At the upper end of model specifications, the Tesla Model S with an 85kWh battery achieves an EPA range of 265 miles (Teslamotors.com, 2013b). PHEVs and REEVs have an extended range due to ICE, making them suitable for longer trips.

The majority of technical experts interviewed for this study currently see BEVs as an urban vehicle primarily used for intra-city travel and commuting. One expert explains, *“While there are exceptions, the large majority of trips made by BEVs are well within the vehicles' battery range.”* The expert continued to explain that the unused portion of the battery capacity is very expensive. *“Consider that a vehicle has an average or regular use and then the exceptional use. When you think of the exceptional use, the vehicle owner pays disproportionately more for that exceptional use and the battery capacity that it requires.”* The extra battery capacity in a BEV allows drivers the luxury of exceptional longer use trips, but it also hedges against the risk of unexpected circumstances, such as getting lost, or not having enough time to fully charge.

The fact that most BEV trips are well within the vehicle's battery range does not necessarily indicate the absence of need or desire for charging infrastructure in areas outside of urban regions. As one expert explained, *“By building out the charging infrastructure system, you start to make the vehicle more functional...Vehicle manufacturers have reported that when you start putting in more infrastructure, you start seeing an uptick in PEV usage and miles driven.”*

Noise: Noise levels of PEVs are much lower than those of conventional ICE vehicles, especially at low speeds (and when the ICE engine is off for PHEVs and REEVs), which principally occurs in urban areas. Thus, PEVs have clear benefits for reducing noise levels from cars. However, this also poses a concern as “silent” vehicles could present a safety hazard for pedestrians (see section 2.5.1).

Cost: PEV prices are considerably higher compared to similar ICE cars in the United States and Europe, as shown in Figure 14 (CE Delft, 2011b). For the actual price distribution (which is not

provided) and the relatively small sample size, a few extremely expensive vehicles skew and inflate the average cost, placing it in the upper quartile for four of the six vehicle categories given.

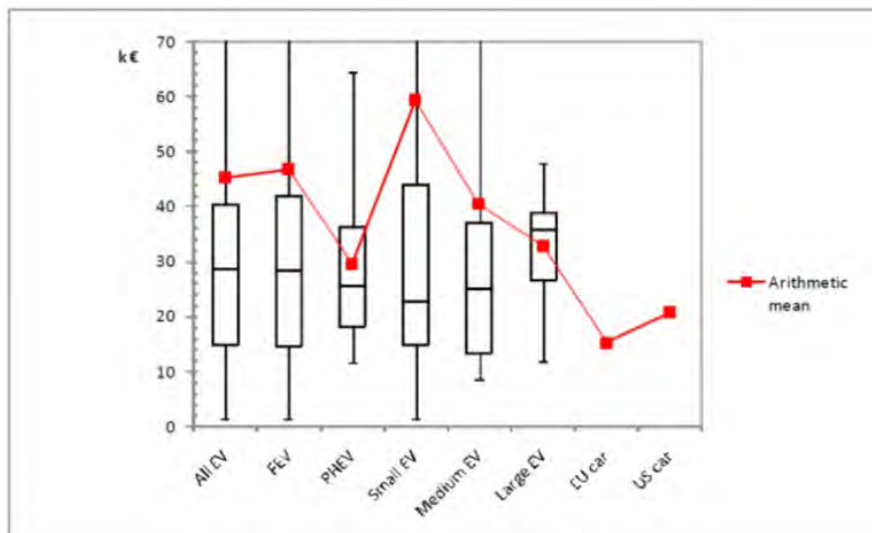


Figure 14: Prices of plug in electric vehicles in Europe

The main reason for the high price of PEVs is the high cost of PEV batteries. Currently, the vehicle drivetrain costs of PEVs are also likely to be higher than those of ICE vehicles due to low production volumes. PHEV/REEV drivetrains are likely to remain more expensive than conventional drivetrains, as they include ICE and electric motors, as well as a transmission system combining both. Pure BEV drivetrains, however, are likely to become less expensive than ICE drivetrains as production volumes rise, due to their relative simplicity and the absence of changeable gears, clutch, etc. A study commissioned by the UK Committee on Climate Change and conducted by AEA forecasts that by 2020, BEV vehicle manufacturing costs excluding the battery could be lower than those of ICE vehicles (AEA, 2012).

While PEVs are likely to remain more expensive to purchase over the coming years, the electricity costs per mile to operate a PEV (in charge-depleting mode) are likely to remain much lower and less volatile than the fuel costs per mile for a conventional ICE vehicle.

Figure 15 shows how electricity prices have remained relatively stable since 1976 compared to gasoline prices. Additionally, a study by Deloitte on the impact of gasoline prices reported that at a price of \$3.50/gallon, approximately 30% of those surveyed said they were more likely to buy a PEV, whereas if gasoline costs \$5.00 /gal, this percentage rises to 78%.

Maintenance costs for BEVs are also expected to be lower due to the reduction or elimination of costs associated with oil changes, drive-train maintenance/repair, and other mechanical elements

of ICE vehicles. Maintenance costs for PEVs mainly depend on the battery replacement frequency.

Because purchase costs tend to be higher and operational costs lower for PEVs compared to conventional vehicles, comparisons should be made on the basis of life-cycle costs. This perspective was highlighted during the panel member interviews. DOE and FHWA representatives pointed out that calculating life cycle costs is complicated by two crucial unknowns: the resale price of the vehicle, and what happens to the battery pack at the end of its life.

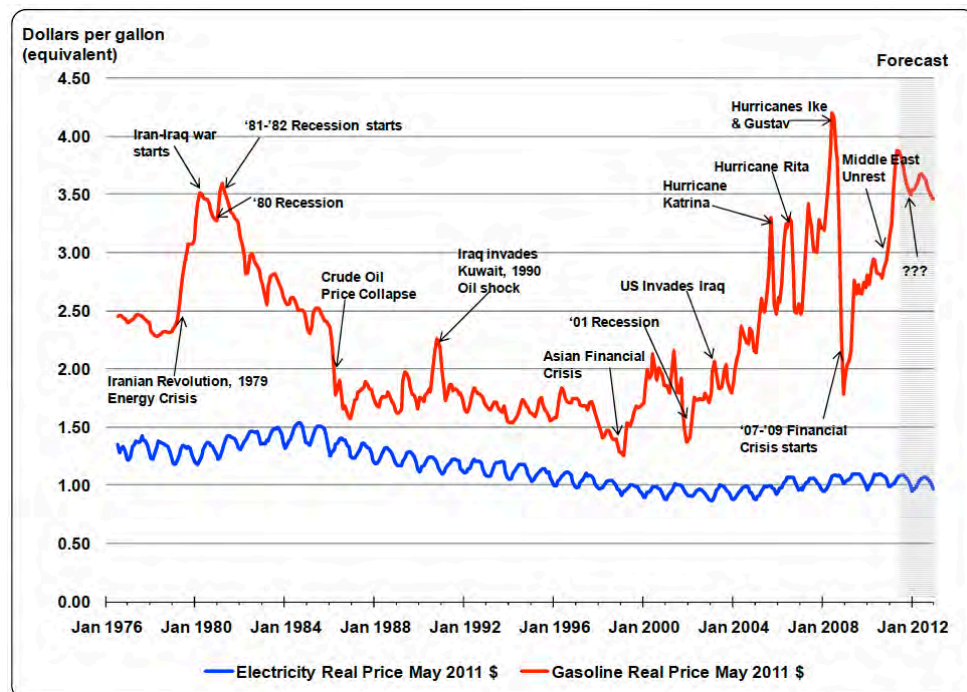


Figure 15: Comparison of gasoline and electricity costs per gallon equivalent.

Source: Edison Electric Institute (EEI, 2011).

Note: Electricity prices are reduced by a factor of 3.4 because electric motors are 3.4 times more efficient than internal combustion engines.

Environmental life cycle analysis: During the foundational research, an expert suggested that costs and benefits of PEVs to the environment (in dollar terms) should be taken into account. For example, it is important to account for environmental impacts from battery manufacturing and disposal, and electricity generation. The Transportation Research Board published an article in 2012 entitled, *Life-Cycle Analysis of Production and Recycling of Lithium Ion Batteries* (Gaines, Sullivan, Burnham, & Belharouak, 2012), discussing the potentially significant impact of recycling battery materials on reducing the amount of total energy needed for material production.

The *Environmental Impact Statement (EIS) for CAFE Standards 2017-2025* was highlighted as a resource for information regarding life-cycle analyses of the overall benefits of PEVs, from production to disposal. The EIS summarizes studies evaluating battery production and upstream electricity generation. The findings conclude that the inclusion of Li-ion battery production impacts results in a larger total environmental impact for PEVs in the production phase of the life cycle than a conventional vehicle (National Highway Traffic Safety Administration, 2012). However, the production phase only represents about 10 percent of the total life-cycle environmental impact (National Highway Traffic Safety Administration, 2012). Table 11 summarizes the findings of the review of multiple EIS life-cycle analyses of energy (Btu per mile) and greenhouse gas (GHG) emissions (grams of CO₂e per mile), comparing PEVs with conventional vehicles.

Table 11: Vehicle life-cycle comparison of energy and greenhouse emissions (National Highway Traffic Safety Administration, 2012)

Environmental Impact Study	Notter et al. (2010)^{2,4}	Notter et al. (2010)^{2,4}	Samaras and Meisterling (2008)⁵	Samaras and Meisterling (2008)⁵	Gaines et al. (2011)³
Vehicle Type	BEV	ICE	BEV (PHEV 30) ⁶	ICE	BEV (PHEV 30) ⁷
Energy Used In Vehicle Production (Btu per mile) ¹	1,140	1,203	610	610	600
Energy Used In Battery Production (Btu per mile) ¹	317	0	76	0	100
Energy Used In Operation (Btu per mile) ¹	3,424	4,827	2,898	4,881	3,800
Total Energy Used (Btu per mile) ¹	4,881	6,030	3,585	5,491	4,500
GHG Emissions used in Vehicle Production (grams CO ₂ e per mile) ¹	67	68	56	56	NE
GHG emissions used in Battery Production (grams CO ₂ e per mile) ¹	19	0	5	0	NE
GHG emissions in Operation (grams CO ₂ e per mile) ¹	175	336	233	377	NE
Total GHG emissions (grams CO ₂ e per mile) ¹	261	404	295	433	NE

Notes:

Values based on an average lifetime mileage of 150,000 miles driven

1. NE = not estimated; BEV = battery electric vehicle; CV = conventional vehicle; Btu = British thermal unit; CO₂e = carbon dioxide equivalent, the normalized unit for GHGs; PHEV = plug-in-hybrid electric vehicle.
2. Vehicle production stage includes maintenance and end of life. Vehicle use stage includes road infrastructure.
3. Energy estimates derived from Figure 5 in Gaines et al. (2011, p. 13).
4. Assumes average electricity production mix in Europe.
5. Assumes U.S. average electricity production mix.
6. PHEV with a 30-kilometer (18.6-mile) all-electric driving distance capacity.
7. PHEV with a 20-mile all-electric driving distance capacity.
8. Use stage includes energy and GHG emissions associated with upstream gasoline and electricity production.

Energy Efficiency: As with conventional ICE vehicles, there are likely to be additional incremental improvements in the overall energy efficiency of PEVs. These improvements could be the result of improved aerodynamics, tires, and light-weighting. In addition, there may be some slight potential for improving energy conversion efficiency. Several European motoring organizations commissioned a study to measure the electricity consumption of several BEVs including the Nissan LEAF, the Mitsubishi iMiEV, and a prototype of the Smart Fortwo Electric Drive under several driving cycles, constant speeds, and ambient temperatures in a dynamometer facility (TU Vienna, 2012). The measurements show that the efficiency of the tested 2011 Nissan LEAF drivetrain at constant speeds at 20–80 mph on a flat road ranges from about 60% to slightly above 70%. Because electric motors have been demonstrated to operate at very high efficiencies above 90% across a wide range of loads and speeds, improvements to electric motors and drivetrain could make efficiencies of 80% or 90% feasible. Additionally, heating in winter can account for a significant share of the PEV’s energy consumption. Measurements by TU Vienna show that the tested 2011 Nissan LEAF uses about 2 kW of power at 32°F. A heat pump system could reduce by 50% the electricity consumption for heating in winter (SAE, 2012). The TU Vienna measurements also show that about 20% of the electricity drawn from the grid is lost in the charger and battery; improvements to the efficiency of the battery and charging system may also be possible.

Material requirements: Another important feature of PEV battery technology that was raised during the panel member interviews and EV Forum is that batteries currently use materials that are a limited global resource, such as cobalt and certain other metals. The same is also true for other parts of the PEV power train—for example, the use of rare earth metal oxides in the electric motors. These critical materials are imported to the United States (principally from China), and consequently, somewhat like petroleum and its products, the need exists for considering and managing security of their supply. The U.S. federal government has been addressing this, and in December 2011, U.S. DOE published a “Critical Materials Strategy” examining the role of these materials in the clean energy economy. DOE’s strategy to address critical materials challenges rests largely on the understanding that diversified global supply chains are essential. To manage supply risk, multiple sources of materials are required, and steps must be taken to facilitate extraction, processing, and manufacturing in the United States, as well as encouraging other nations to expedite alternative supplies (US Department of Energy, 2011).

Sixteen elements and related materials were selected for a criticality assessment undertaken in 2011. Eight of the elements are rare earth metals, which are valued for their magnetic, optical, and catalyst properties. Many of the materials are used in clean energy technologies such as PEV batteries and electric motors, and include the elements lanthanum, cerium, praseodymium, neodymium, nickel, manganese, cobalt, and lithium (US Department of Energy, 2011).

2.2 DRIVER CHARACTERISTICS AND EXPECTATIONS

2.2.1 Private owners

Consumers considering the purchase of a PEV evaluate traditional factors such as cost, reliability, performance, and aesthetics, but also PEV-specific usability considerations. In *Ready, Set, Charge, California!* the authors flag several questions on which, beyond traditional vehicle purchasing decisions, potential PEV owners will likely want answers (Ready Set Charge California, 2011):

- How long does charging take, and how much will it cost?
- How many PEV charging stations are available in my area?
- Is it easy to get a residential PEV charger installed in my garage?
- How will I charge if I live in an apartment or condominium?
- Will I receive any kind of driving privileges by driving a PEV, such as HOV lane access?
- Will my employer provide workplace charging?
- When will my car's battery wear out, and if so how will I replace it?
- What can I do if I break down on the highway or in a strange town?

In general, the experts had differing opinions about PEV customer expectations and preferences. One expert observed that social media has facilitated a robust dialogue about PEVs and helps customers become familiar with the technology. Because PEV drivers are emotionally connected to their vehicles and the technology, they want to share their experience. Another expert raised concerns about the effects on PEV acceptance when certain privileges such as free public charging are eliminated.

During the panel member interviews, the DOE representative pointed to two general social trends that might negatively affect private PEV purchases:

- Many medium-income U.S. households cannot afford to buy new vehicles, let alone expensive PEVs (Duncombe, 2013).
- The percentage of young people without a driver's license has been increasing in the United States over the past 30 years, particularly in recent years (Sivak & Schoettle, 2012).

U.C. Davis's Institute for Transportation Studies found that early adopters' reasons for EV purchases included symbolic values such as "a strong ethical belief to protect the environment or oppose war," "a desire to reduce dependence on foreign oil," "an assertion of individualism and to embrace new technology," and "gaining social standing" (Reid R. Heffner et al, 2007).

Communities and regions that include relatively large numbers of individuals who are collectively aware of these issues and motivated to implement related change would also likely be the same communities that will be first to develop EV related infrastructure and provide additional support for household adoption of EV technology. Moreover, research (Axsen et al, 2009) based on both hybrid vehicle sales over time in Canada and stated preference surveys in California has shown that “neighbor effects” play a role in a person’s consideration of the purchase of a hybrid vehicle. If survey participants are asked to make a hypothetical vehicle purchase decision in a scenario in which the market share of hybrids is already at 10% or 50%, their willingness to pay for a hybrid vehicle increases. The same is likely to be true for PEVs. When the impacts of infrastructural requirements for BEVs are also taken into account, it is very likely that a given “critical mass” of BEV ownership in a community will encourage accelerated further adoption.

There are a number of publicly available surveys that classify the demographics of near-term EV customers. Two of these surveys were reviewed for this work: California Center of Sustainable Energy’s *California Plug-In Electric Vehicle Owner Survey* (Center for Sustainable Energy California, 2012); and ZPryme’s *The Electric Vehicle Study* (Zpryme, 2010). These studies reached similar conclusions:

- The majority of early adopters are male.
- Owners typically live in two-person households.
- Most also own a conventional, gasoline-powered vehicle and single-family home.
- Financial reasons have more weight in the purchase decision than other factors such as environmental protection.
- Those likely to purchase an EV were more environmentally concerned than those not likely to purchase an EV.
- Respondents exhibited a very high frequency of online activities and use of associated technologies.

In the expert interviews for the present study, one expert described early BEV adopters as “purists” not wanting to have an excuse to use gasoline: “*The inconvenience that BEV drivers are willing to accept is high.*” Similarly, another expert described Chevrolet Volt owners as having “gas anxiety” instead of range anxiety, meaning they try to avoid using their gasoline engine, leading to multiple charges per day.

2.2.2 Fleets

Fleet vehicles make up a small percentage of total vehicles on the road, but drive more miles and consume more fuel than the average passenger vehicle (C2ES, 2012). Fleets often feature characteristics that would make them potentially well suited for electrification. These characteristics may include high utilization rates, regular fixed routes, refueling at the same place every night, and the “green branding” offered by using PEVs for delivery. Fleets often have greater purchasing power and may be able to negotiate a lower purchase price for a bulk purchase. Additionally, fleet managers may be more likely to look at the full life-cycle cost

benefit of electric vehicles compared to traditional ICE powered vehicles and be willing to pay a higher upfront cost in exchange for overall savings (Electrification Coalition, 2009). Nissan originally predicted that about 90% of PEV sales would be from fleet purchases. This prediction was proven wrong, as private consumers rather than fleet buyers have purchased the majority of Nissan LEAFs sold thus far. Challenges for fleet operators may include the uncertainty around residual battery value and the local power requirements when charging many fleet vehicles at the same location simultaneously. Moreover, public fleets cannot benefit from the substantial tax credits for PEVs because they have no tax liability (Nick Nigro, 2012).

Despite the early establishment of this trend, fleet vehicles still have the potential to provide a pathway to the general consumer market and engage consumer segments that might otherwise not initially choose a PEV. Research presented at TRB in early 2014 (Bradley Lane, 2013), reflected user surveys of household and fleet consumers in Indianapolis with different implications. Lane's research demonstrated that fleet consumers are more likely to view a PEV as a task-oriented vehicle, are more likely to adapt and integrate a PEV's capabilities into their everyday usage patterns. PEV manufacturers recognize the importance of the fleet vehicle market segment. As an example, Tesla, in early 2014, announced a fleet leasing program for small and medium-sized businesses and will also provide vehicle financing (Green Fleet, 2014b).

The allocation of budget and responsibilities across organizations still remains a barrier for fleet consumers. Unlike more conventional fleet purchases, one person will be generally not able to adequately identify all of the benefits and costs involved in making a PEV purchase. PEV fleet purchases generally require a wide analysis that brings together needs from different spheres of interest such as fleet managers, facilities, energy management, communications, safety and finance to meet collective goals (e.g., vehicle performance needs, recharging and power infrastructure, organization image, training to reduce risk, and total cost of ownership) (Nesbitt and Davies, 2013).

2.3 CHARGING STATIONS

2.3.1 Charging station levels

Currently, there are three charging levels/rates available for Electric Vehicle Supply Equipment (EVSE), the equipment used to deliver electricity to a PEV:

Level 1: Level 1 Alternating Current (AC) is compatible with all PEVs. This is the typical home charging option, with supply equipment included with the purchase of the new vehicle. Level 1 charging stations provide charging through a 120V AC plug. Most if not all PEVs will come with a Level 1 charging station cord set, so that no additional charging equipment is required. On one end of the cord is a standard grounded, three-prong household plug (NEMA 5-15 connector). The other end is a J1772 standard connector. (An adapter may be needed between the J1772 connector and the EV charge point.) Level 1 is typically used for charging when there is only a 120 V outlet available. Based on the battery type and vehicle, Level 1 charging adds

approximately 4–5 miles of range to a PEV per hour of charging time (Alternative Fuels Data Center, 2012)⁸.

Level 2: Level 2 Alternating Current (AC) is compatible with all PEVs; it requires additional equipment and installation modifications by a trained, licenced electrician, and costs approximately \$2,000 when installed at a home. Level 2 equipment offers charging through a 240V (residential applications, commonly used for electric dryers and stoves) or 208V (commercial applications) outlet. Depending on requirements, Level 2 charging stations come with a dedicated circuit providing 20–80 amps. This option can operate at up to 19.2kW. Most residential equipment will operate at a lower current of approximately 30A, delivering 7.2kW requiring a 40A circuit. Level 2 equipment uses the same connector and adapter as Level 1 equipment. Based on the battery type and circuit capacity, Level 2 charging equipment adds about 10–20 miles of range per hour of charging time, depending on the vehicle (Alternative Fuels Data Center, 2012).

DC Fast charging: Direct Current (DC) Fast charging (also known as Level 3) converts AC to DC “off-board,” so currently only BEVs can use this option. It is the most expensive option to purchase, install and operate because of more expensive parts and necessary electrical upgrades. Therefore, it is unlikely to be available for home charging. DC Fast charging equipment (480-V AC input) enables rapid charging suitable for heavy traffic corridors and at public stations. A DC Fast charge can add 60–80 miles of range to a light-duty BEV in 20 minutes (Alternative Fuels Data Center, 2012).

Unlike Level 1 and 2 charging, there is no single agreed standard for DC Fast chargers, but rather several competing systems, so connections and charging rates associated with DC Fast chargers vary across several proprietary systems. However, activities are underway to generate DC Fast charging standards.

Infrastructure requirements for DC Fast charging also vary. The necessary rate of charge transfer cannot occur conveniently from a domestic single phase supply. Many suppliers of charging stations use a three-phase supply; however this is not the only possibility. Recent research has focused on buffering the charge between the grid and the connection to the PEV (evcollective.com)⁹. This is tantamount to having a Level 1 charging system (as seen by the grid) that charges the vehicle like a Level 3 Fast charging system. One way to achieve this is to use a conventional group of lead-acid batteries, slowly charge them from the grid, and then rapidly discharge them as the charge is transferred to the battery in the PEV. Another advantage of this approach is that it can be combined with off-grid electricity production, e.g. wind or solar power,

⁸ Source gives the figure 2–5 miles range/hr, but at expert review it was commented that this was an anomalously low figure.

⁹ See for example, information on the website: <http://www.evcollective.com/charger/BB50KW.html> While the power requirement for the chargers indicates a 3-phase supply is required, contact with the company indicates they anticipate the facility to charge the using a single phase supply by October of this year, and the single supply phase product should then show up on the webpage.

further reducing the strain on the grid. Select Tesla Supercharger stations use solar power as their primary energy source (Teslamotors.com, 2012) .

Verified installation of proper charging equipment is often required by car manufacturers for consumers to be eligible to purchase their products. For instance, Nissan requires prospective purchasers of the LEAF to either have a home charging unit installed by Nissan's exclusive contractor, AeroVironment, or sign a waiver certifying that they have installed their own charging equipment (Center for Automotive Research, 2011b). Of note, PEV manufacturers such as Nissan are offering novel programs to remove cost barriers. Nissan has expanded its “No Charge to Charge” pilot program, giving its Nissan Leaf owners the flexibility to charge for free across a number of public charging networks (e.g., ChargePoint, Blink Network, AeroEnvironment and NRG eVgo) for the first two years of ownership (hybridcars.com, 2014).

The typical U.S. charging times for different charging levels are given in Table 12.

Table 12: Typical PEV charging times at different charging levels, and equipment and installation costs (Plug In America, 2012a)

Charger Type	Charge to	Chevy Volt 16 kWh	Mitsubishi i-MiEV 16 kWh	Nissan LEAF 2 kWh	Charge Hardware Cost	Installation Cost	Estimated Total Cost
AC Level 1 1+ kW 120 VAC	Half	5 hrs	8 hrs	10 hrs	\$100–500	\$100–500	\$200–1,000
AC Level 1 1+ kW 120 VAC	Full	10 hrs	16 hrs	20 hrs	\$100–500	\$100–500	\$200–1,000
AC Level 2 3.3+ kW 240VAC	Half	1.5 hrs	2.5 hrs	3 hrs	\$500–1,500 home and \$2,000–6,500 commercial	\$500–2,500 home and \$3,000–5,000 commercial	\$1,000–4,000 home and \$5,000–11,500 commercial*
AC Level 2 3.3+ kW 240VAC	Full	3 hrs	4.5 hrs	6 hrs	\$500–1,500 home and \$2,000–6,500 commercial	\$500–2,500 home and \$3,000–5,000 commercial	\$1,000–4,000 home and \$5,000–11,500 commercial*
DC Fast 50+ kW 100-600VDC	Half	N/A	10 min	20 min	\$10,000–30,000	\$5,000–30,000	\$15,000–60,000*
DC Fast 50+ kW 100-600VDC	Full	N/A	30 min	45 min	\$10,000–30,000	\$5,000–30,000	\$15,000–60,000*

Note: Reductions in equipment and installation costs between 2012 (Table 12, Plug In America) and 2014 (Table 13, Rocky Mountain Institute), particularly for AC Level 2 and DC Fast chargers.

Rocky Mountain Institute (RMI) released research findings in May 2014 that uncover the different types of costs associated with equipment and installation costs (e.g., charging station

hardware, electrician materials and labor, transformer, mobilization and permits). Of note, costs for AC Level 2 chargers have declined notably in two years' time. Level 2 home and commercial charger prices have come down 30-50% in the two years between the studies. Curbside charger costs remain comparable and this is most likely due to urban streetside infrastructure impediments. DC Fast charging systems remain equal or more expensive. RMI's work also identifies the opportunity for group purchasing of multiple stations, which can provide additional cost reductions. Figure 16 and Figure 17 below share parking garage and curbside charger installation costs by category, in thousands of dollars (Rocky Mountain Institute, 2014). Given the downward cost trends for certain charging infrastructure, it is worth monitoring equipment and installation costs and how those prices translate to breakeven or cost-benefit decisions for PEV owners and charging infrastructure providers.

Table 13: Typical equipment and installation costs (Rocky Mountain Institute, 2014)

Charger Type	Charge Station Hardware	Electrician Materials and Labor	Other Materials and Labor	Transformer	Mobilization	Permits	Estimated Total Cost
AC Level 2 Home	\$450-1,000	\$150-500	\$0	N/A	\$50-200	\$0-100	\$650-1,800
AC Level 2 Parking Garage	\$1,500-2,500	\$1,450-3,450	\$300-850	N/A	\$250-500	\$50-200	\$3,550-7,550*
AC Level 2 Curbside	\$1,500-3,000	\$950-1,800	\$2,550-7,650	N/A	\$250-500	\$50-200	\$5,350-13,150
DC Fast	\$12,000-\$35,000	\$1,900-3,600	\$5,100-15,400	\$10,000-25,000	\$600-1,200	\$50-200	\$29,050-80,400*

Note: Reductions in equipment and installation costs between 2012 (Table 12, Plug In America) and 2014 (Table 13, Rocky Mountain Institute), particularly for AC Level 2 and DC Fast chargers.

Source: (Rocky Mountain Institute, 2014)

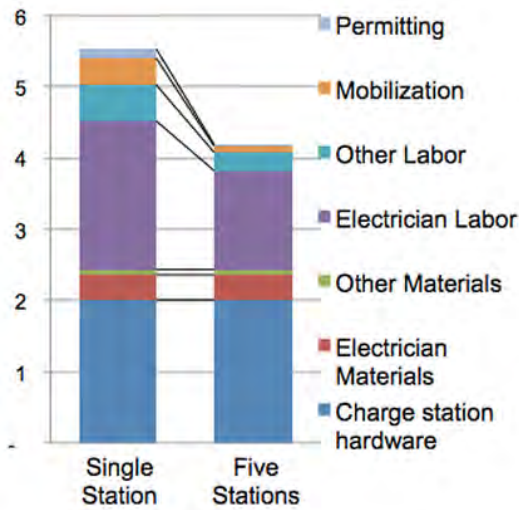


Figure 16: Parking Garage Installation Costs (in thousands of dollars)

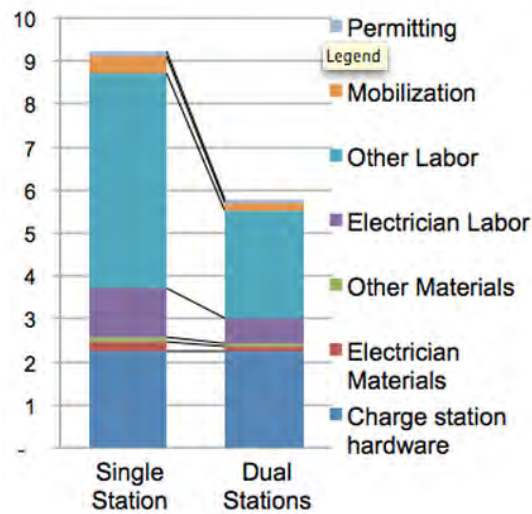


Figure 17: Curbside Charger Installation Costs (in thousands of dollars)

2.3.2 Charging station locations

The location of stations where users charge their BEVs is important and affects charging behavior, the economics of charging, and also planning for investment in charging infrastructure networks. These locations can be categorized into three classes (Clinton Climate Institute, 2010):

Home charging: Home charging includes charging at user residences, such as in the garages of single family homes and multi-unit apartment complexes, as well as on-street residential spaces. Home charging is expected to be a combination of Level 1 and Level 2 charging used to charge PEVs overnight. Charging station installations must comply with local, state, and national codes and regulations. Appropriate permits may be required from the local building, fire, environmental, and electrical inspecting and permitting authorities.

Workplace charging: Workplace charging can occur in outdoor office garages, commercial complex parking garages, etc., and is expected to be Level 1 and Level 2. This is considered one of the most important locations for providing charging in order to extend PEV range, given that it is one of the most frequent routes travelled.

Public charging: Public charging stations increase the usability and convenience of all-electric vehicles. They can also be viewed as a safety measure for reducing the likelihood of stranded vehicles and as a means to overcome drivers' "range anxiety." Although the majority of PEV owners will charge at single-family homes, public charging stations can increase the useful range of PEVs and reduce the amount of gasoline consumed by PHEVs and REEVs. Public charging will generally use Level 2 or DC Fast charging. Various types of public charging exist that may require different considerations—for example, Right of Way (ROW) charging, retail, parking garages, motels, public property, etc.

When developing the various PEV deployment scenarios and considering the charging of vehicles (see later Section 3.2), this research characterized vehicle charging as:

- At home or at work.
- At local destinations, using publicly accessible chargers.
- Mid-trip, using publicly accessible chargers on or near the Interstate ROW.

Shopping malls were analyzed as representative locations when determining the suitability of local destinations for providing the required power for PEV charging. Level 2 charging is assumed, and shopping malls generally already have the required three-phase supply in place, as well as the required parking availability.

Rest areas are obviously an important potential location for publicly accessible chargers on or near the Interstate ROW. However, as discussed later in 2.3.5.3, without significant investment in infrastructure, policy/legal clarifications, and changes in rest area operational practices, the majority of Interstate charging will be most likely to occur at multi-use commercial facilities at Interstate exits, rather than at rest areas.

Experience with current BEV pilot projects indicate that more than 90% of charging events occur at home, but the existence of public charging infrastructure may be important for reducing "range anxiety" and therefore instrumental to increasing the adoption of BEVs (Bakker, 2011). Moreover, during the EV Forum, discussions focused on the relevance of charging infrastructure as a safety measure for reducing the likelihood of stranded vehicles (see Section 2.5.1).

During the expert interviews it was observed that current charging infrastructure is predominantly Level 2 charging equipment. The reports on the EV Project, the largest study on

the deployment of electric vehicles and charge infrastructure in history funded by DOE, is an important source of information that summarizes charging patterns in the EV Project's study areas (Idaho National Laboratory, n.d.).

Table 14 provides a summary of the charging events captured by the EV Project for the total study area that took place from October 2013 through December 2013 (Idaho National Laboratory, 2013). As evidenced in the report, the large majority of charging events take place at residential locations with Level 2 chargers.

Table 14: Charging data from all regions of the EV Project for October 2013 through December 2013

Charging Unit Usage	Residential Level 2	Private Nonresidential Level 2	Publicly Available Level 2	Publicly Available DC Fast	Total
Number of charging units	5,106	336	2,521	95	8,058
Number of charging events	401,497	15,938	70,278	11,704	499,417
Electricity consumed (AC MWh)	3,088.36	184.80	584.35	108.79	3,966.30
Percent of time with a vehicle connected to charging unit	43%	19%	6%	2%	30%
Percent of time with a vehicle drawing power from charging unit	8%	8%	3%	2%	6%

2.3.3 Charging station standards

Level 1 and Level 2 AC chargers are compatible with all PEVs and can be used at home. The Society of Automotive Engineers (SAE) J1772 standard—adopted on January 14, 2010—details the physical and electrical characteristics of the charge system. All major vehicle and charging system manufacturers support this standard in the United States, and the standard should eliminate drivers' concerns about whether their vehicle is compatible with the infrastructure. The standard defines a five-pin configuration used for Level 1 and Level 2 charging and designed to survive more than 10,000 connection and disconnection cycles (IA-HEV, 2009). This corresponds to a greater than 10-year lifetime for the vast majority of levels of usage. This standard has been accepted by all potential PEV manufacturers in the United States.

However, for DC Fast charging (like the Nissan LEAF and Mitsubishi i-MiEV) a variety of plug and socket configurations exist, with no single standard adopted. There are currently three different standards in the United States for fast-charging:

- **SAE Combo** Level 2 & DC, which was approved in October 2012.
- The Japan-based **CHAdeMO**.
- **Tesla Motors** proprietary standard.

Given these different standards, there may be future compatibility issues for high-current chargers (C2ES, 2012). All current Nissan LEAFs with fast charging capabilities are compatible with the CHAdeMO DC Fast charger connector standard, while American vehicle manufacturers have committed to using the new SAE Combo connector standard. It is unknown whether Nissan will convert to the SAE Combo standard. During the expert interviews, one vehicle manufacturer asserted that the majority of vehicle manufacturers with PEVs coming to market have indicated they will use the SAE Combo standard. The third DC Fast charger technology being installed in the United States is in Tesla's Supercharger stations. As of May 2014, Tesla had built 91 Supercharger stations in 26 states and is anticipating that by the end of 2014, 41 states will have Supercharger stations installed. Tesla's next goal is that by the end of 2015, 98% of the United States population will be within 100 miles of a Supercharger station (Teslamotors.com, 2014a). Tesla also made a significant announcement in June 2014, as it opened all its electric car patents to outside use in order for other firms to use their technology, which would lead the way to other manufacturers use of similar charging technology, thereby mutually benefiting Tesla and other manufacturers if the other manufacturers adopt the standards of Tesla (Teslamotors.com, 2014b).

One charging station manufacturer representative described its approach to the competing standards as simply following the market, claiming to be somewhat ambivalent to the standard itself.

“The problem it creates is now you have two competing standards. It creates confusion in the market. It is very expensive to support two different technologies.”

All fast chargers currently installed in the United States, except for Tesla's Superchargers, follow the CHAdeMO standard. These stations include the West Coast Electric Highway project and Ecotality installations. Several state and U.S. DOE fast charging projects plan to have the charging station manufacturers make the units usable for all vehicles with fast charging capabilities, but it is not yet clear how this universality will be accomplished.

These varying standards could lead to a situation in which a PEV driver needs to recharge, finds a charging station, but cannot access the electricity because the car is not compatible with the connector. The need for common standards for electric vehicle charging is becoming clear, not only for safety issues, but because the use of a common standard will make it less expensive to establish electric vehicle charging stations.

2.3.4 Charging station business models

The PEV charging market is in an early stage and therefore highly volatile. There is uncertainty as to which technical standards and business models will succeed. There are also many new companies entering the market. For example, it is anticipated that there will soon be well over 80 different charging station models available (Pike Research, 2012a). Several business models for charging stations are plausible, ranging from subscription-based charging and open pay-as-you-drive charging to free charging, and would also depend on location. Free charging may, for example, be feasible in combination with retail parking, with electricity costs funded by

shopping revenues. However, experience is showing that the charging station market is commercially challenging.

The alternative to in-vehicle battery charging is battery swapping, which involves replacing the depleted battery with a fully charged battery in a matter of minutes. This approach—alongside DC Fast charging (Supercharging)—is being pursued by Tesla, but is not without its challenges. Better Place was one of the early pioneers of battery swapping. In this commercial model, Better Place owned the batteries and used robotic switching stations in place of charging. This vision attracted a number of blue-chip investors, but despite this funding, Better Place filed for bankruptcy in May 2013.

During the panel member interviews, a state DOT representative emphasized the challenge associated with finding a successful charging station business model. Subsidies may be necessary, as it is unlikely that the cost of infrastructure could be recovered through electricity sales if people can charge at home at considerably lower rates. It is feasible that over time, as charging away from home becomes more commonplace, the dramatic price differentials between grid power and transportation power will equalize.

In the expert interviews, opinions diverged on whether a network of charging stations is required, and to what extent such a network should be publicly funded. However, experts tended to agree that building a viable business model that recovers costs is challenging, especially for fast charging. If utilities were also to apply demand charges (charges for the *possibility* of taking a given amount of power (kW) from the grid) to fast charging station operators, this would further compromise commercial viability. Experts, however, expressed the view that locations with retail amenities are likely to be important for a successful business model, especially if the charging station encourages customers to spend more time (and thus money) in adjacent shops and restaurants.

2.3.5 Demand for publicly accessible charging stations

The demand for installing publicly accessible charging stations depends on:

- The type of PEV (i.e., BEVs, PHEVs, or REEVs).
- The geographic distribution of current PEV users and future potential purchasers.
- Where the charging station is located—whether publicly accessible on or near the Interstate highway system, publicly accessible at local destinations away from the Interstate, or at home or work.

These are explored in the following three subsections.

2.3.5.1 Demand considerations related to type of PEV

For PHEV and REEV users, factors to consider when determining the possible demand for installing publicly accessible charging stations include:

- Drivers of these vehicles do not have to use publicly accessible charging points if the vehicle has traveled outside the battery's charge-depleting range, because the vehicle can use its ICE. This flexibility is contrasted with BEVs, which do require charging if the vehicle travels outside the battery's charge-depleting range.
- They may use publicly accessible charging if there is a benefit. For example, if the electricity is free, if there is a conveniently placed charging station, and if the driver (plus any passengers) needs to stop in the vicinity of the charging point for other reasons, then drivers may choose to connect their vehicle to the publicly accessible charger. The Idaho National Laboratory (INL) analysis of the behavior of Chevrolet Volt users indicates that convenience and low cost encourage use.
- If there is a cost associated with charging, PHEV and REEV owners' charging decisions will be related to the cost, since they have a choice about whether or not to charge. The cost of gasoline will be considered along with the cost of charging, with a higher differential between gasoline and electricity prices encouraging electric charging.
- If there are government mandates or incentives to reduce fossil fuel use, publicly accessible charging may be more attractive than using the ICE.

Due to the above factors related to PHEVs and REEVs, focusing on BEVs is the best approach for determining the implications for different travel markets and the demand for installing publicly accessible charging stations.

BEV users will likely be selective about the journeys for which they use their BEVs. At least until BEVs obtain substantially greater range, owners will likely use second vehicles with an ICE, if available, for longer journeys. Charging options away from home and work will be a critical factor in encouraging BEV use, particularly for longer trips.

For long-distance trips on the Interstate, BEV users charging at publicly accessible charging stations at Interstate rest areas or commercial locations near the Interstate will naturally want to charge as swiftly as possible. This will most conveniently be accomplished using a DC Fast charging system. It is presumed this would require about a 24-minute charging window, in what is assumed to be a 30–40-minute stop in the near term, during which the vehicle will be charged sufficiently to travel about 60 more miles. A 30–40-minute charging break provides a reasonable duration for a break, although drivers are unlikely to need such a long break after driving only 60 miles on the Interstate (which would take about an hour). The frequent charging could be helpful in assuring that drivers are rested, but such frequent stops will likely be a deterrent to long PEV trips, particularly if drivers have to use busy freeway interchanges to find charging stations. Charge times may be reduced in the future if fast charging protocols and hardware lead to higher charging rates than the current 50 kWh per hour rate.

For charging at publicly accessible charging stations at local destinations, Level 2 charging may be sufficient. Adding approximately 30 miles of additional range could be accomplished in under

two hours (now and likely for some time into the future). It is anticipated that while the vehicle charges, the vehicle occupants might occupy themselves by shopping or dining at a restaurant.

2.3.5.2 Demand considerations related to geographic distribution of PEV users and future potential purchasers

PEVs tend to be located in “hotspots” across the country. The concentration of PEV sales is influenced by political, cultural, and geographic factors.

Political factors include policy incentives such as local or state governmental tax credits, PEV use of HOV lanes, and building codes that accommodate the use of the vehicles. According to a leading PEV manufacturer, sales for its PEVs doubled with the introduction of a new incentive, and increased to 350% of baseline sales when two or more incentives are bundled (NISSAN, personal communication). Currently, the greatest political support for the proliferation of PEVs is concentrated in the Northeast, Mid-Atlantic, and West Coast states, driving a higher level of adoption of PEVs in those regions.

Urban density is also a factor in PEV adoption. Greater urban densities allow the vehicle’s range to reach more of the essential services and conveniences of daily life. Conversely, rural and more sprawling suburban and exurban areas may result in range concerns that limit PEV use. The NHTS provides a breakdown of vehicle ownership according to population density (Figure 18), showing that people living in areas with high population density generally own fewer vehicles, and those living in areas with lower population density generally own more vehicles. Because daily VMT is lower in areas with higher population densities, the data seem to support the assertion that higher urban densities are more conducive to PEV use. Research on hybrid electric vehicles also demonstrates beneficial fuel efficiency, particularly in low speed, urban environments (Zahabi et al., 2014).

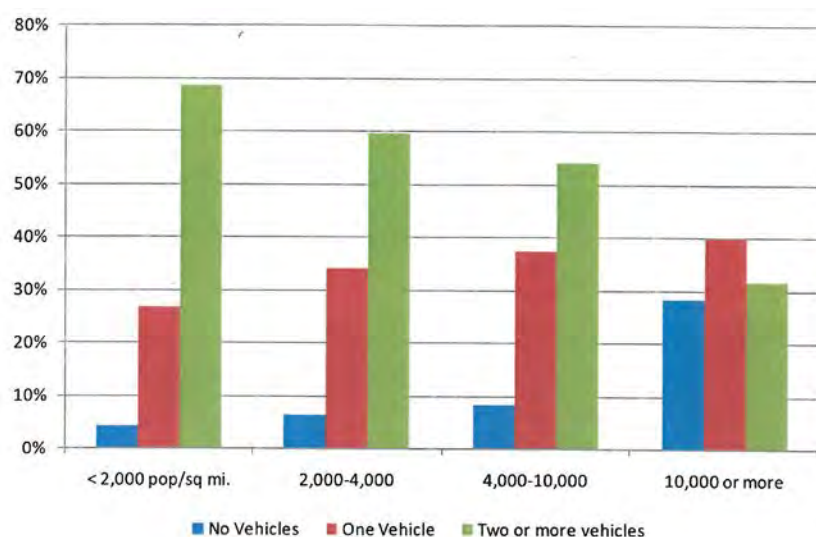


Figure 18: Percent of households by vehicle ownership and population density (from 2009 NHTS)

Finally, geographic and climatic conditions affect the functionality of PEVs. Temperate climates and flatter landscapes are more conducive to efficient PEV use—particularly BEVs. Colder and hotter climates reduce the range, and therefore utility, of PEVs due to impacts on battery performance. Mountainous terrain also reduces the range due to the additional power required to climb hills.

Among these geographic factors, temperature may affect battery performance enough to impact adoption rates and market penetration in any given regional market. In dynamometer testing of several BEVs by TU Vienna (TU Vienna, 2012) it was found that temperatures significantly affect range while a mild 2% uphill-downhill topography does not greatly affect range (see Table 15)¹⁰. During the expert interviews, a charging station manufacturer representative argued that in very cold weather, a standard Level 1 charger can barely charge the battery, as most of the energy would be needed to keep the battery warm.

AAA also evaluated PEVs under cold temperatures and discovered that, on average, PEVs can lose 57 percent of their range due to low temperature. PEVs that obtain an average of 105 miles of range at 75 degrees Fahrenheit dropped to 43 miles of range at a steady temperature of 20 degrees. ORNL found that ICE vehicle efficiency dropped by approximately 12 percent at a constant temperature of 20 degrees Fahrenheit. Hybrids experienced declines of 31–34 percent in fuel economy. PEV range loss can also be attributed to powering the climate control system, but alternatives such as heated seats and preheating the vehicle during its charge prior to driving can reduce this impact. The Nissan LEAF added a heat pump to the 2013 model year to reduce the demand on the battery and now offers a heated steering wheel and heated seats on all its LEAF models (AAA, 2014).

Table 15: Range of 2011 Nissan LEAF under various temperatures and driving cycles (TU Vienna, 2012)

Driving Cycle	Ambient temperature	Vehicle range in miles: Nissan LEAF	Vehicle range in miles: Nissan LEAF +/- 2% gradient
NEDC Extra-urban	+86°F	71	68
NEDC Extra-urban	+68°F	75	70
NEDC Extra-urban	+50°F	69	65
NEDC Extra-urban	+32°F	61	58
NEDC Extra-urban	+14°F	52	50
NEDC Extra-urban	-4°F	45	43
NEDC urban	+86°F	66	65
NEDC urban	+68°F	84	82
NEDC urban	+50°F	62	60

¹⁰ Note that the New European Driving Cycle (NEDC) cycle measurements undertaken by TU Vienna resulted in significantly lower range than the official NEDC range of 175km quoted for the 2011 LEAF. The original table had temperatures in °C and distances in kilometres. The constant speed was 50 kph.

Driving Cycle	Ambient temperature	Vehicle range in miles: Nissan LEAF	Vehicle range in miles: Nissan LEAF +/- 2% gradient
NEDC urban	+32°F	45	44
NEDC urban	+14°F	35	35
NEDC urban	-4°F	27	27
Constant speed 31 mph	+86°F	98	104
Constant speed 31 mph	+68°F	108	116
Constant speed 31 mph	+50°F	92	98
Constant speed 31 mph	+32°F	76	80
Constant speed 31 mph	+14°F	63	65
Constant speed 31 mph	-4°F	52	54

Notwithstanding the above issues, it is expected that there will be technological responses to the limits of current batteries, which should help mitigate these climatic and topographical challenges.

Example geographic distribution of PEV purchasers

The geographic distribution of Nissan LEAF purchasers (the highest volume selling BEV) is shown in Figure 19. This sales map reflects the factors described above to some extent, with clustering in temperate regions with substantial tax credits (e.g. California), and dense urban areas such as Washington, D.C., New York City, and Chicago.

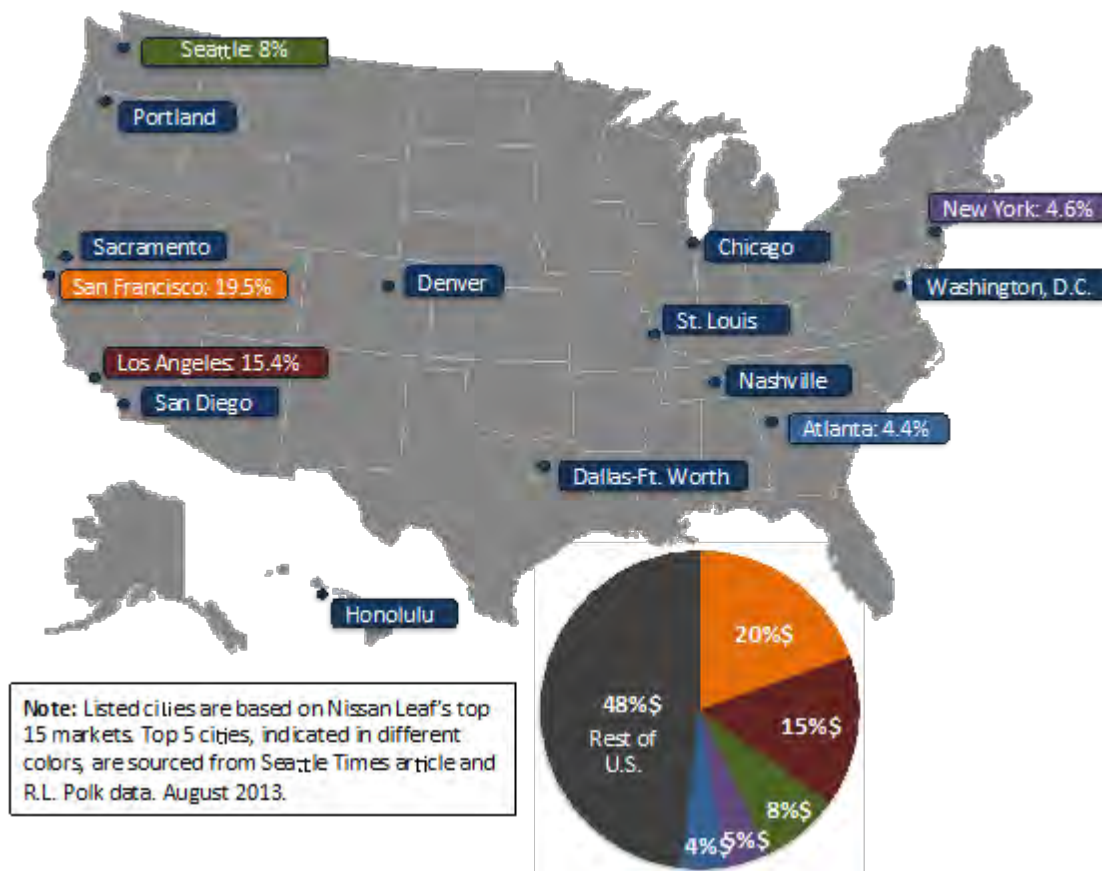


Figure 19: Top U.S. EV markets

2.3.5.3 Demand considerations related to location of charging stations

Publicly accessible charging stations on or near the Interstate highway system

Both the pace of PEV adoption and the composition of the evolving PEV market have implications for government policy regarding support for building a network of publicly accessible charging stations located at convenient intervals on or near the Interstate highway system.

Interstate charging is expected to represent a very small portion of all PEV charging initially. Therefore, based on demand alone, a broad network of charging stations across the Interstate highway system does not appear to be justified in the short-term. Because most PEVs are likely to be charged at home and work, and because most owners are likely to use a second car for trips that exceed the charging distance, ICEs are likely to be used for most long-distance trips. In addition, early adopters are more likely to be informed and “tech savvy,” and therefore less likely to feel the need for a proliferation of charging stations to ameliorate range anxiety.

By 2030, however, we can expect to see both an increasing number of PEVs and an increasing number of intercity trips carried out using those PEVs—especially if the range is increased and the charge time is reduced to a duration that would be considered acceptable during a typical trip. The market will also change, as early adopters make way for the “early majority.” Early majority drivers may be less adventurous than early adopters and more prone to range anxiety. The combination of these factors—growing proliferation of PEVs, improved suitability of PEVs for longer-range travel, and an increasing number of PEVs drivers likely to have range anxiety—may make a strong case for promoting an intercity charging station network by 2030.

After 2030, the trends of an increasing number of PEVs and an increasing number of intercity trips carried out using those PEVs are expected to continue. These trends were taken into account in the development of scenarios during this research, and the project has deliberately included significant Interstate charging, especially for 2040 and 2050, to evaluate the possible implications.

There are strong arguments in favor of promoting the development of an intercity network in advance of market forces. These arguments include:

- By directly confronting the problem of range anxiety, the rollout of a significant charging network could hasten the market transition between early adopters and the early majority, thereby accelerating PEV adoption.
- By making all-electric long-distance travel practical, a robust charging network could improve the market share of BEVs, advancing both climate change and energy conservation goals.
- With all-electric long-distance travel becoming more practical, many households may feel less need for a “backup” ICE vehicle—in addition to generating fewer ICE miles, one-vehicle households typically generate less total VMT than multi-vehicle households.
- The development of a true long-distance network, perhaps based on the Interstate highway system, could serve as a visible sign of the commitment of federal and state governments to vehicle electrification.

When considering a publicly accessible charging station network on or near the Interstate highway system, the logical place to start would be along intercity corridors connecting cities with the highest current sales of PEVs. Some options for Interstate charging stations include:

- Publicly funded charging points at rest areas (for example, the free charging stations installed in Washington State).
- New commercial charging points at rest areas (although as noted below, this would require an amendment to 23 USC 111).

- Commercial charging points at rest areas where commercial development is already allowed, including toll roads (e.g., the Pennsylvania Turnpike) and “grandfathered” non-toll Interstates (e.g., I-95 in Connecticut).
- Off-ROW commercial locations (e.g., travel plazas, truck stops, gas stations, and tribal rest areas, such as along I-5 in Oregon).

Rest areas: Rest areas provide universal access for rest, traveler information, and restroom facilities. Benefits include improved safety through reduced driver fatigue, avoidance of vehicles parking on highway shoulders, and refuge from adverse driving conditions (in addition to non-safety benefits such as increased tourism). AASHTO guidelines recommend locating rest areas at intervals of approximately 60 miles on the Interstate system (Californian Department of Transportation (Caltrans), 2011), although actual spacing varies, and in recent years some states have closed rest areas due to funding constraints. As mentioned above, DC Fast charging currently enables an additional 60 miles of travel to be attained with a 24-minute charge (though it is assumed that the vehicle will be on the charging station parking area for 30–40 minutes). This matches well with the possibility of installing charging stations at rest areas spaced approximately 60 miles apart, although this implies stopping for 30–40 minutes for every hour of driving. Unfortunately, the legal landscape makes this an unlikely option, as discussed further in Section 2.9.1.1.

Commercial locations: Multi-purpose commercial truck stops and gas stations are typically located at Interstate exits and are where most long-distance travelers currently stop for food, fuel, and supplies. With relatively good access (“easy-off” and “easy-on”), existing signage, and a robust electricity supply, these facilities offer some of the most promising potential locations for charging stations.

Publicly accessible charging stations at local destinations

For non-Interstate publicly accessible charging locations there are a number of options:

- Parking lots at venues where the public spends multiple hours at a time, such as shopping malls, restaurants, and government buildings.
- Parking lots at venues where the public stays for longer periods of time (more than a few hours), such as tourist attractions, theme parks, etc.
- Parking lots at venues where people stay overnight, such as hotels, motels, and bed-and-breakfasts.
- RV parks, truck stops, marinas, and other similar locations that are already equipped to provide charging to some extent.
- State, county, or local rest areas, public parks, and waysides that are not on the Interstate highway system.
- Transit stations and park-and-ride lots.

As noted above, publicly accessible charging stations at local destinations would likely use Level 2 charging. This would allow approximately 30 miles of additional range to be added in under two hours—a reasonable amount of time for shopping, dining, etc.

Charging locations on private property—such as those at shopping malls, restaurants, theme parks, motels, and other commercial properties—may impose constraints on some PEV owners. For example, some venues might be for patrons only, some may be at locations that certain users do not need to visit, some may not be open or may be available only at certain times, and others may prohibit the presence of pets. This issue informs the debate regarding the need for charging stations that are on publicly accessible property—whether at state DOT rest areas, city parks, or county waysides—particularly with respect to the need for a minimum charging “safety net.”

Home and workplace charging

This research considered residential and workplace charging together, rather than separately. The research assumes that each PEV will require one residential charging point. This assumption might change with multiple PEV ownership per household, but because there are more than 113 million households (from 2009 National Household Travel Survey, NHTS), the assumption is likely to hold for all but the later years of the most aggressive scenarios analyzed. Workplace charging is likely to be required by some PEV owners with longer commutes. It is anticipated workplace charging stations would be predominantly Level 1 or Level 2 charging, with the longer charging times being acceptable because vehicles would often be left parked for the whole working day. The NHTS indicates that commuting to and from work represents approximately 28% of VMT (Table 6 of 2009 NHTS), with an average trip length of 12.2 miles. The regular commute to work is predictable and is likely within the vehicle’s electric range, and therefore is an important aspect of PEV use. Consequently, in the scenario analysis, the research team estimated that the required number of workplace charging points is 10% of the PEV deployment number. Further information on the issues that employers should consider when assessing whether to offer workplace charging for employees is provided in a recent publication from the DOE Clean Cities Program entitled PEV Handbook for Workplace Charging Hosts (US Department of Energy, 2012c).

While most PEV owners charge at home, development of workplace charging is viewed as a potentially important consideration for prospective PEV buyers. Two recent studies have quantified the costs of workplace and away-from-home charging. A University of California Los Angeles study determined that employers that installed a PEV charging infrastructure would need to charge \$35/month or \$1.25/hour of active charging in order to break even on their investment. This pricing regime is unlikely to motivate employee drivers to charge away from home if they were to bear the true costs (Williams and DeShazo, 2013). The University of Buffalo has performed research to measure individual-level PEV owner inconvenience costs associated with operating and recharging with different charging systems. Using a value of time of \$30 per hour, an average inconvenience time cost for PEV owners for daily trips over 60 miles is \$47–50 per day for AC Level 1 charging infrastructure and \$6–10 for AC Level 2 infrastructure (Kang and Recker, 2014). These types of inconvenience costs will lead PEV drivers to rely more heavily on charging at home.

2.3.6 Electric Power Research Institute (EPRI) analysis of U.S. charging needs

Research generated by EPRI proposed a U.S. nationwide EV charging network, represented on the map shown in Figure 20¹¹. This analysis was originally generated to answer the question of whether or not the number of charging stations would need to equal the number of existing fueling stations nationwide, estimated at over 100,000. EPRI determined how many stations would be needed to serve 99% of the U.S. population with charging stations within 20 miles.

The red dots represent proposed “town locations.” For these 4,267 locations, EPRI assumed that any city with a population of 2,000–100,000 should have at least one charging *location* (could be more than one charging station), for example, in the town center or in front of City Hall. EPRI assumed that cities with more than 100,000 people will develop their own charging networks. The blue dots represent proposed “safety locations.” Once the proposed town-based network is complete, these “safety locations” would then be provided to cover major roadways across the United States. The number of stations (1,336) is based on an assumed spacing of 20-mile intervals¹². These potential station locations have not been correlated to rest areas, interchanges, popular destinations or retail areas. Further, they were intended to cover unspecified roads, highways, or interstates between or near the “town” population centers, and were not based on VMT or interstate travel trends.

The “town locations” and “safety locations” concept could also be described as a “clusters and corridors” approach to an EV network. Charging stations in the clusters may be provided in multiple ways (e.g. home, work, commercial locations, etc.), but charging stations in the corridors connecting those clusters may require some government support. When asked what level of charging station network would be required to meet current demand, EPRI personnel suggested developing charging stations along the corridors between the major cities and towns, with the largest clusters of vehicles and charging stations already deployed in the area. This scenario would represent the lowest potential level of government charging station deployment support.

The proposed EPRI “safety” network, as it was originally conceived, is rather extensive. The proposed coverage is far larger than the Interstate system, which is likely the most pertinent system for long-distance travel. The network appears to be even larger than the National Highway System network and would create the conditions for anyone with a PEV—no matter how short-range and no matter how rural the area—to have a charging station close at hand. EPRI personnel have indicated that “accelerating deployment” may be a more appropriate term for this extensive deployment of charging stations than “safety network.”

¹¹ Private Communication; map kindly provided by M Davis and M Duval, EPRI, October 2013. Also further communication with Morgan Davis and Daniel Bowermaster in February, 2014. This research is included here as it appears to be a unique example of such a systematic, nationwide analysis.

¹² While the EPRI study is based on an assumed spacing of 20-mile intervals, this study concludes that intercity corridors between dense PEV and charging stations cities require about a 25–60 mile interval between stations. (See section 4.1.2.2)

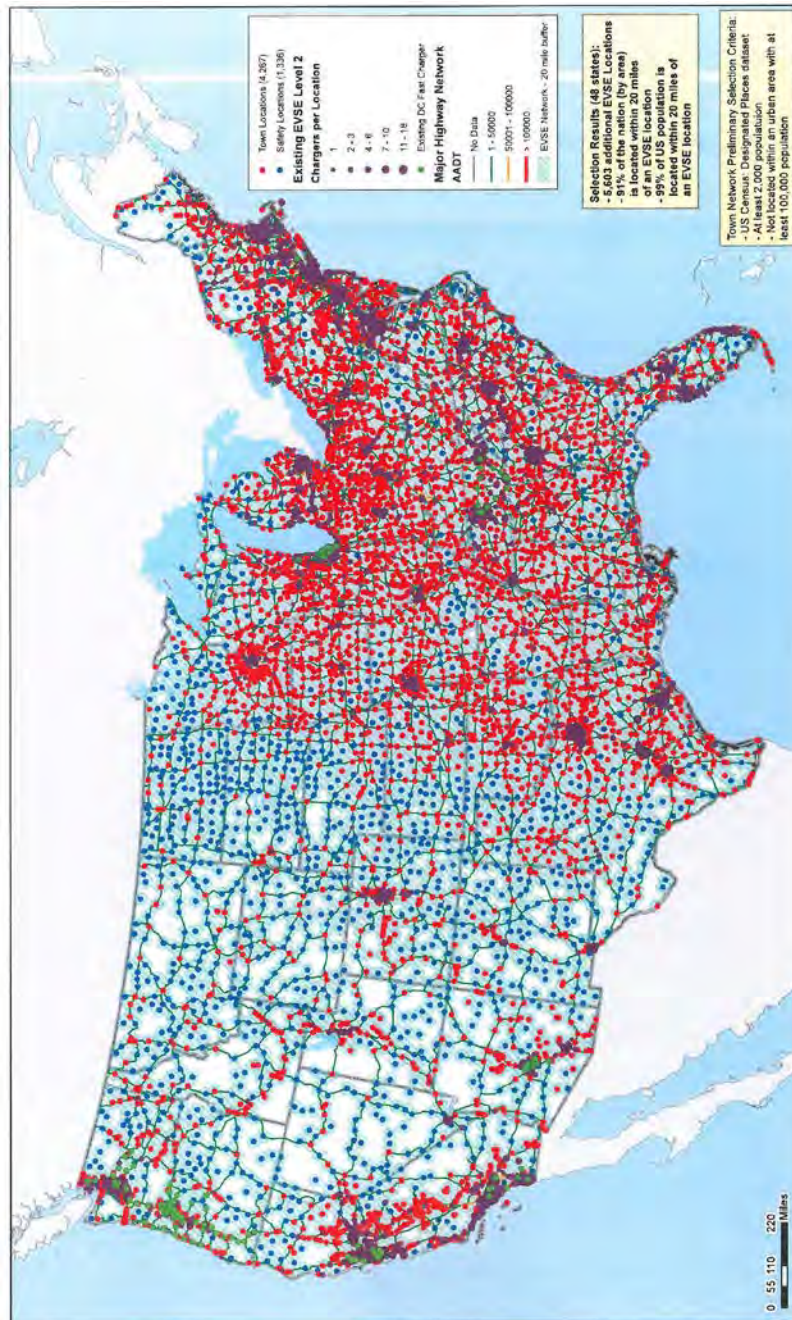


Figure 20: EPRI proposed U.S. Nationwide Charging Network

A simple estimate of total infrastructure development cost for the proposed EPRI network is approximately \$67 million, based on an installed DC Fast charging station cost of \$50,000 for 1,336 stations. This estimate assumes that appropriate real estate and infrastructure exists for this network, and assumes the provision of one charger per station.

2.3.7 Role of utilities in charging

Utilities play a central and critical role in the deployment of PEVs and developing the associated infrastructure. *“Considering that infrastructure investments in the electric grid often have a decades-long time span, the extent of market growth in 2030 or 2040 echoes investments and deployment strategies put in place today”* (Nick Nigro, 2011). (EPRI, 2011) sees the following key roles for utilities:

Charging infrastructure and services: Perhaps the greatest role any utility can play is providing public charging infrastructure and supporting the installation of private charging infrastructure while meeting the associated technical challenges (e.g., in terms of grid load). Utilities will also be responsible for the development of Smart Grid technologies that will facilitate particular aspects of PEV implementation, such as:

- Metering PEV electricity consumption.
- Implementation of time-of-use pricing.
- Customer programmed off-peak charging.
- Integration of intermittent renewable electricity generation (School of Public and Environmental Affairs at Indiana University, 2011).

In addition to capital infrastructure, utilities could also offer customer assistance and emergency services related to the critical charging infrastructure.

During the expert interviews, utility representatives noted that they are already actively engaging with the challenges that PEVs pose to the grid. For example, GM and Nissan (the current PEV market sales leaders) notify utilities of PEV sales so they can assess in advance whether adjustments to the grid are needed. Generally, residential charging from a larger number of homes causes more concern than DC Fast charging stations. Experts also pointed out that DC Fast charging in rural areas may be difficult to realize, as often there is no three-phase power available, so only limited power can be taken off the grid. One expert examined multiple rest stops, finding that none were suitable as DC Fast charge sites, due to lack of access to available power.

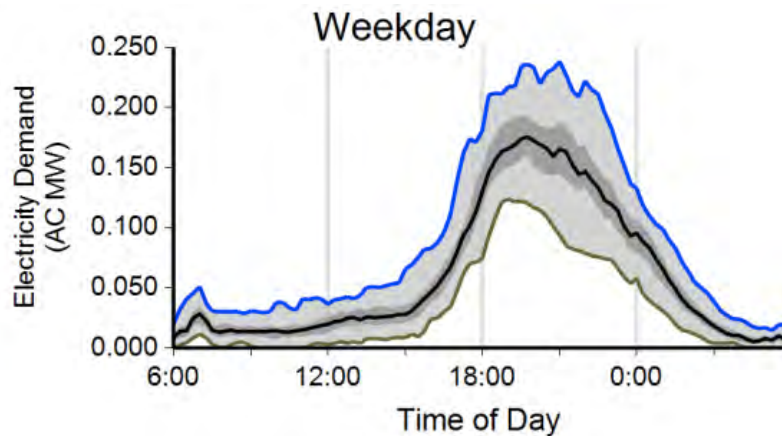


Figure 22: Weekday Residential Charging Demand in NES Territory

Source: (Ecotality and Idaho National Laboratory, 2013)

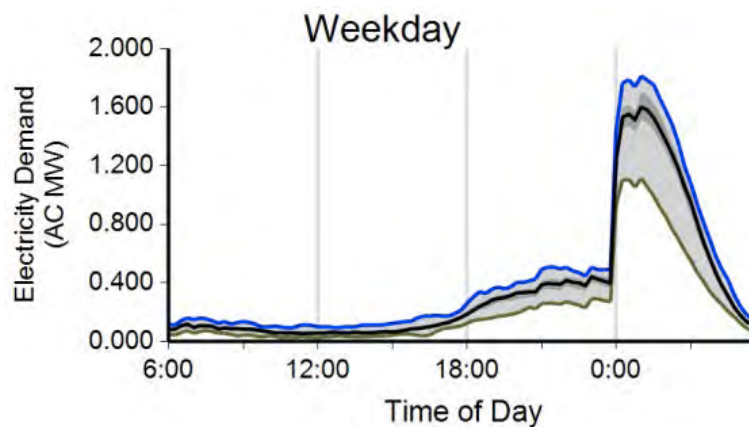


Figure 21: Weekday Residential Charging Demand in PG&E Territory

Source: (Ecotality and Idaho National Laboratory, 2013)

Ecotality and Idaho National Laboratory (INL) published a study of PEV owner home charging habits with and without time-of-use pricing. PEV owners without time-of-use pricing start recharging at roughly 6:00 P.M., whereas those subject to time-of-use pricing generally start charging around midnight – the time of lower rates. As shown in Figure 22 and Figure 21, this distinction can be identified clearly in the figures that show charging patterns in Nashville Electric Service (NES) territory (no time of use pricing) and Pacific Gas & Electric (PG&E) which has time-of-use pricing (Ecotality and Idaho National Laboratory, 2013). A PEV Collaborative study indicated that households with EVs tend to shift charging to off-peak, unless the household has a solar photovoltaic (PV) system, which makes them far more likely to charge at their convenience. A subsequent PEV Collaborative study confirmed that households with PEVs tend to shift charging to off-peak, unless the household has a solar photovoltaic (PV) system, which makes them far more likely to charge at their convenience (Kurani et al., 2013).

Experts were also concerned about the variety of state regulations, for example on the ability of utilities to own and operate charging infrastructure. In Oregon, the Public Utility Commission (PUC) ruled that if charging services are not otherwise provided, utilities may be able to fill that gap in supply. Conversely, in California, the PUC assumes third parties will meet charging infrastructure needs and therefore concludes utilities should not own or operate them.

Customer education and outreach: Surveys have demonstrated interest in PEVs but a lack of general understanding about how they work. Utilities can play a role beyond vehicle dealerships as a source of information in their communities about PEVs and their infrastructure.

Research, demonstration and development: The establishment of new infrastructure should be an organized and carefully tested process. Unfortunately, real-world information is largely disorganized. Utilities can play a key role in supporting the deliberate coordination of the necessary parties to accelerate the adoption of PEVs. Utilities have the ability to pilot new technologies and share this information, establish requirements, and work with vehicle manufactures and other technology providers to test promising concepts, such as matching renewable electricity sources with overnight PEV charging demands.

2.3.8 Future advancements in charging

2.3.8.1 Battery swapping

Given that battery charging can take several hours, and that fast charging can be detrimental to battery life, battery swapping stations at which batteries are switched out—in about the same time it takes to refuel a car—is also an interesting option for PEV users. In June of 2013, Tesla announced plans to provide battery swapping stations that would switch out batteries in Tesla cars in 90 seconds (businessweek.com, 2013). Yet one month earlier, in May of 2013, BetterPlace—the pioneer of BEV swapping stations, operating approximately 40 stations in Israel and Denmark—filed for bankruptcy. Customer demand was much lower than projected and clearly insufficient to recover the high cost of investment in the swapping stations (Quartz, 2013). In the expert interviews, one of the experts advocated a battery swapping system, while many others saw it as cost-prohibitive to scale up, and considered it unlikely that vehicle manufacturers would agree to select battery models that could be swapped out easily.

2.3.8.2 Advanced metering and grid management

Charging a PEV involves considerations beyond the plugs connecting the electric vehicle, the physical charging point, and the voltages and currents used, including aspects such as protocols for transaction initiation, acceptance, and payment. These issues are generally not relevant for home charging, because the house occupants are automatically monitored and billed, but they are for publicly accessible charging. It is anticipated that these protocols will develop and be standardized alongside the increased availability of charging stations. In essence, publicly accessible charging stations need systems in place to:

- Identify that an authorized electric vehicle user is ready to recharge a vehicle.

- Display the pricing agreement information.
- Display the amount of charge transferred.
- Ensure proper metering of the electricity consumed.
- Ensure secure payment.

For home charging, future evolution of charging systems is likely to involve “smart charging”—i.e., charging during periods of low demand on the grid. Smart charging may also involve returning electricity from the battery back into the grid in periods of high demand (also known as vehicle-to-grid or V2G). An increased use of “submetering” for PEV charging at home garages may also facilitate the use of differential rates for PEV charging, data collection for grid management purposes, and tax collection for jurisdictions that may choose to use (as Pennsylvania does) an alternative fuel usage tax. Daily recharging for a commuter with an electric vehicle could follow one of three patterns:

- Arrive home and place vehicle in charge mode.
- Arrive home, plug vehicle in for recharge and let a smart meter delay charging until the peak evening surge in demand has subsided.
- Arrive home, plug vehicle in for recharge and let a smart grid system augment the grid supply using some power remaining in the battery to help meet the peak evening surge in demand, and then recharge after this surge in demand has subsided.

A report on “Drivers and inhibitors of Electric Vehicles” – based on data from a live test fleet of EVs in Denmark – states that “intelligent power grid management (smart grid) is necessary to avoid overloading the electrical grid at peak hours when charging EVs” (MEC Intelligence, 2011). This would, however, only become true when the numbers of PEVs deployed becomes significantly larger than current levels or near-term projections.

2.3.8.3 Inductive charging

In addition to the charging via cables already discussed (using Level 1, 2, or DC Fast charge protocols), a further advance in charging technology that may occur is wireless charging (Smolaks, 2012). This is often referred to as “inductive charging.” It uses an electromagnetic field to transfer electricity to a PEV without a cord. This process can occur when the vehicle is stationary (static wireless charging) or while the vehicle is in motion (dynamic wireless charging), with the latter being the more technologically challenging. An important feature of inductive charging is the ability to simplify and streamline the process for the public charging stations that would be ADA compliant, and reduce confusion around plug types.

Plugless currently offers an inductive charging system for Nissan Leaf and Chevrolet Volt models with energy transmission rates will be similar to those for a Level 2 charger running at approximately 3 kW. Other examples of inductive charging systems include Volvo and Volkswagen, which announced in May 2014 that it anticipates offering an inductive charging system for its PEV models by 2017 (Green Fleet, 2014c). Toyota has partnered with Audi and Mitsubishi via WiTricity, an MIT spinoff, to develop a wireless charging system. WiTricity anticipates having an inductive charging system available by 2016 (Triple Pundit, 2014).

Currently available PEV passenger cars are not equipped for inductive charging, although it has been demonstrated. One example is a company in Virginia that is demonstrating wireless charging of Nissan LEAF and Chevrolet Volt vehicles (Plugless Power, 2012). The limited technical information available suggests energy transmission rates will be similar to those for a Level 2 charger running at approximately 3 kW.

Inductive charging has also been demonstrated for transit buses, which have well defined routes and stopping points. Utah State University has demonstrated a system drawing energy wirelessly from a power source under the vehicle. Proterra Inc., based in South Carolina, has developed an automated rooftop inductive charging system that transfers charge at 500 kW, providing an additional 20 miles of range in 10 minutes.

Pike Research predicted real deployment of wireless inductive charging could take place as soon as 2013. That prediction was overly optimistic. Initial deployment will be in sales of retrofit units—estimated to cost \$2,500—for existing vehicles. A company called Evatran plans to offer wireless charging retrofits for both the Chevy Volt and the Nissan LEAF. Other companies entering the wireless charging market are looking at commercial introduction between 2013 and 2015 (Pike Research, 2012a). In terms of safety, inductive systems may offer some safety advantages because there are no exposed conductors. However, inductive systems are slightly less efficient than conductive methods.

If energy transmission rates can achieve charging times close to those of DC Fast charge stations via wires, new possibilities arise for some vehicles operated with regular stops. For example, electric taxis might be able to take on significant charge during waiting time at a dedicated taxi queue, which could extend the range of taxis.

During the expert interviews, when asked if dynamic charging (wireless charging) will be a reality in the future, one expert's response was, *"People keep talking about solutions that would be ideal in the future, however we are still struggling to do the basics. People are talking about how expensive PEVs are, and all of these other future technologies are very expensive."* Another expert believes we will see substantial battery improvements before we see wireless charging, making dynamic charging technology less important to market development. Others point to the importance of supporting pilot studies that examine this and other technologies to determine their real world application value.

A final important consideration is standards for inductive charging. SAE International is developing a standard that may apply in the future.

2.4 HIGHWAY DESIGN STANDARDS AND INFRASTRUCTURE

A key premise of this analysis is that PEVs are, for the most part, replacements for conventional ICE vehicles. PEVs are not anticipated to create a different, additional market, or lead to an expansion of the total number of vehicles that would otherwise be using the nation's roads. PEV weights are currently approximately comparable to their ICE counterparts. Current design standards for infrastructure (including lane configurations and pavement types) already

accommodate PEVs, and non-standard design features are not anticipated. However, policies do exist (and could be expanded) to allow special use of certain infrastructure to encourage adoption—such as allowing PEVs to use HOV lanes. These policies have implications for signage and law enforcement.

2.5 SAFETY, EMERGENCY SERVICES, AND INCIDENT RESPONSE

2.5.1 Electric vehicles and safety

2.5.1.1 General in-use vehicle hazards

Concerns have been expressed regarding the hazards associated with electric vehicles when involved in crashes or in the case of a vehicle fire. These arise because lithium burns in air, and reacts with water quite vigorously. However, there is growing evidence that these concerns may be overemphasized. During a National Highway Traffic Safety Administration (NHTSA) investigation into Chevrolet Volt vehicle fires, it was found that PEVs were unlikely to pose a greater risk of fire than gasoline powered autos. This assessment was echoed during one of the expert interviews. During the expert interviews it was pointed out that increased numbers of BEVs will result in fewer combustible fuel storage tanks, thus creating a safer roadway.

Some jurisdictions have instituted training for first responders to better equip them. The National Fire Protection Association has produced an on-line electric vehicle safety training document for fire fighters and first responders. During the panel member interviews the DOE representative suggested an effort to standardize and implement first responder training throughout the country for dealing with EV crashes.

The most common safety concern raised in the expert interviews was the potential for PEVs to run out of battery power and break down in the middle of traffic. Two experts spoke to this concern and gave personal examples about running out of battery power while driving. However, one state DOT representative said, *“While that was a big concern early on, common sense would tell you we do not see a lot of people running out of gas, and PEV drivers are even more aware of range.”* One suggestion was to mandate a “limp mode” that reserves battery power to allow the driver to get to the side of the road prior to the vehicle being completely discharged.

In order to reduce the risk of BEVs getting stranded it was recommended by a representative of the DOE that there should be systematic placement of uniform standardized way-finding signs to guide drivers to recharging points (as already developed by Oregon and Washington State and just adopted by California). The safety relevance of publicly accessible charging infrastructure along with a standardized signage system was also emphasized at the EV Forum. Signage should follow the FHWA’s manual on uniform traffic control devices (MUTCD) policy (MUTCD, 2003). It was also argued that the main purpose of public charging infrastructure was to provide insurance against stranded vehicles.

2.5.1.2 Collisions

There are concerns expressed by various safety groups that the relative silence of a PEV's electric motors presents a safety hazard to pedestrians and/or animals, potentially causing more collisions. However, this potential concern needs to be considered in the context of the following points:

- There is a general trend for all vehicles to become quieter.
- The “silence” of PEVs is easily remedied by fitting vehicles with a sound generation device that activates when the vehicle is moving and/or preparing to move.

The current trend appears to be moving towards a vehicle-based solution, i.e. fitting PEVs with a sound source, as the most practical implementation measure. The National Highway Traffic Safety Administration (NHTSA) has undertaken an assessment which outlines a proposal on rules for vehicle sounds (National Highway Traffic Safety Administration, 2013). While sound generation is technically straightforward, some type of regulatory framework may be required to enforce implementation. Under 49CFR571, NHTSA has filed a notice of proposed rulemaking for minimum sound requirements for hybrid and electric vehicles (Docket # NHTSA-2011-0148; Regulation Identifier Number 2127-AK93). A summary of the NHTSA current research activities regarding electric vehicles is given in Appendix E: “Summary of research by NHTSA on EVs.”

It is generally accepted that vehicles and people should be separated, especially in locations where vehicle speeds are higher. The introduction of PEVs does not alter this. Indeed, at higher speeds, where road and tire noise become louder than engine noise, PEVs (whether or not they are operating under electric power) are not much quieter than their ICE equivalents. It is in urban areas, at low-vehicle speeds (and where the ICE engine is more likely to be off for PHEVs and REEVs) where electric motors are considerably quieter than their conventional equivalents.

Collisions with animals may pose an additional safety issue for PEVs because of quietness and lack of warning. Of particular concern are migration corridors of land mammals, where they may be caught off-guard by a quiet vehicle. These safety concerns are likely to be addressed, at least in part, by modifications intended to make vehicles safer for pedestrians.

2.5.1.3 Charging infrastructure safety

Another aspect of PEVs that represents a safety risk is during “refueling”, i.e. charging. Electric connections, both with household supplies at 110 V AC (Level 1) or 240 V AC (Level 2) require precautions, especially when making connections outdoors where there is the possibility of inclement weather and cable damage. Potential safety concerns regarding PEV charging infrastructure include:

- The importance of charging stations being installed by suitably qualified licensed electrical contractors. (This was stressed during the panel member interviews by the DOE

representative. It was suggested that Article 625 of the Electrical Code should be referred to for charging station installations and adopted as the standard for building codes.)

- The design of the charging stations in terms of adhering to the Americans with Disabilities Act (ADA) guidelines. Good design is also important with regard to the charging cord height and weight. Additionally, it is important to place the cord in a location where it is not a trip hazard. (It was noted that the Ohio and Virginia EV Readiness reports (Drive Electric Ohio, 2013, Richmond EV Initiative, 2013) have relied upon ADA guidelines.)
- General electrical safety that has to be considered when plugging in any item to 240 V AC (Level 2) or for a DC Fast charging (Level 3) system. Fast charging may involve up to 250 kW of power. The high energy density leads to high temperatures and a need for cooling of the battery and charging structure.
- The additional hazard of making connections outside, where there is the possibility of rain or damaged cords being encountered. The use of ground fault circuit interrupters (GFCI) can offer considerable protection in these circumstances. During the winter, hazards include difficulty of handling charging cords under snowy and icy conditions, slippery footing, and the potential for damage to cords from snow plowing.
- The possibility of PEV owners driving away while the charging cord is still attached, which could become more problematic with increased PEV deployment, and increased pressure to vacate charging points in a timely fashion. Safety systems can help reduce the likelihood or implications of this.
- Infrastructure vandalism or theft could be a problem in less secure locations or in areas where metal theft is already an issue.

Many of these potential concerns can be addressed through a combination of good design, the adoption of standards, and regulatory requirements. In the future, if inductive systems become widely used, it is anticipated they could be safer in some regards.

2.5.2 Emergency services and incident response

Increased deployment of PEVs—particularly BEVs—may result in an increased number of stranded vehicles, due to the use of unfamiliar technology by new drivers and initially low levels of publicly accessible charging stations. As noted above, ICE vehicles have a “range” as well, but stranded ICE vehicles that have run out of gas are relatively uncommon. While NHTSA statistics capturing the number of stranded motorists are not available, AAA state that they “came to the rescue of over 600,000 motorists experiencing fuel related problems in 2012.”(AAA, 2014) This represents 1.1% of their membership needing service per year related to fueling problems.

More stranded PEVs will lead to more demand for rescue. Options available for stranded PEVs include:

- Towing.
- Charging.
- Swapping batteries.

AAA, the most widely known roadside assistance service in the United States, has been piloting roadside emergency charging for electric cars (Alysha Webb, 2011). AAA is running a one-year pilot project, using six units fitted with one of three different technical approaches, in California, Florida and Washington. The recovery vehicles will be equipped with Level 2 chargers, as well as DC Fast chargers for vehicles that feature the CHAdeMO charging protocol. AAA understands that there are currently a limited number of BEVs on the road, but intends to use this pilot project to learn which technology works best and is the most durable.

State DOT emergency responders as well as other first responders such as local fire and police departments may need additional training and guidance on dealing with PEVs. This will provide confidence to the emergency responders in how to deal with the unique technologies associated with PEVs, and will provide reassurance to PEV drivers. To this end, new national guidance has recently become available, which provides an online safety training course for first responders (NFPA, 2012).

In addition to emergency responders, second responders such as tow truck operators will also require training. Examples exist of tow truck drivers refusing to tow PEVs, citing anxiety about damaging the “unfamiliar” vehicle.

2.5.3 Broader human health benefits

Beyond the safety concerns listed above, there are various safety and human health benefits associated with the use of PEVs. Large-scale deployment of PEVs in urban areas could reduce local air toxics over time. Traffic noise concerns may also be reduced. The extent of the impact will depend on what portion of total VMT in a given area is being accomplished through the use of PEVs running on electric motors with no tailpipe emissions (and reduced road noise at lower speeds).

2.6 SIGNAGE, INFORMATION NETWORKS, AND ONLINE MAPPING SERVICES

Currently there is signage defined in FHWA’s Manual on Uniform Traffic Control Devices (MUTCD). This contains the two characters “EV”, as shown in Figure 23. Following further standardization of DC Fast charging protocols, signage for publicly accessible charging stations may need to be refined to designate Level 2 or DC Fast (Level 3) charge stations, with no designation for Level 1 charging. Given that space exists for a third character (the current MUTCD sign for CNG refueling contains three characters), the current EV sign could be augmented with the number 2 or 3 (or both), to indicate the type of charging available.



Figure 23: Electric vehicle charging sign as defined in FHWA's MUTCD

Signs are useful in helping to identify that a charger is nearby. However, wayfinding signage may be more necessary, given that charging stations do not require a large retail complex that is easily spotted while driving.

Surveys that classify the demographics of current PEV users show that they exhibit a very high frequency of online activities and use of associated technologies. This indicates that online, mobile communication technologies could be used to augment standard roadside signage. Charging station maps do exist (e.g., <http://www.plugshare.com/>), but need to be kept current with the latest ESVE information. The data presented should also include the type of charging system, the plug type, and whether or not the charging station is open to all users (as opposed to only drivers of certain vehicles or members of a particular group). The data should be presented in such a way as to be useable on mobile devices and GPS navigation systems.

2.7 ENERGY SECURITY

At the 2014 Annual Meeting of Transportation Research Board, two research papers discussed the role of PEVs in energy security. In short, PEVs can participate in improving the energy security position of the U.S. by reducing world prices for all oil through substitution and reducing the potential for oil disruptions to the U.S. economy through decreased dependence. Energy security can be described as protecting the economy from risk of short- and long-term increases in energy costs. High oil import costs due to a non-competitive oil supply and vulnerability to large price shocks are two central energy security issues. One trend that has emerged in the past few years, and is anticipated to continue over the next few decades, is decreasing energy imports (Figure 24). This shift is due to greater domestic energy production, such as the natural gas boom, as well as continued increases in energy efficiency (Greene, 2014).

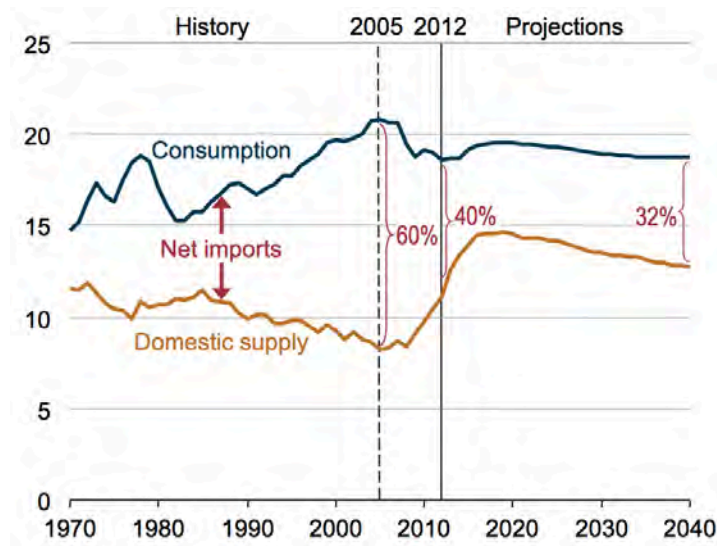


Figure 24: U.S. petroleum and other liquid fuels supply, 1970–2040 (million barrels per day)

Source: (EIA, 2014 Early Release)

As the authors from U.S. EPA and ORNL shared, there are physical characteristics to oil and electricity that lead directly to energy security implications:

- Oil is a “fungible commodity” meaning that it is a material that can be easily transported overseas, and is not limited to being transported only over land like electricity. Therefore, electricity produced in a country or region stays in that area and thereby increases energy independence. Further, due to the fact that electricity is produced domestically the use of electricity for PEVs reduces oil import costs. This in turn reduces exposure to oil disruptions (Leiby et al., 2014).
- U.S. electricity is not reliant upon oil supply and therefore electricity production does not vary with oil prices. Petroleum currently accounts for ~0.3% of U.S. total electricity generation, and according to AEO that figure is anticipated to drop to 0.1% by 2040. Additionally electricity prices are more stable than petroleum prices.
- Transportation accounts for nearly 50% of global oil demand, or 44 million barrels per day (mb/d). Of that daily demand, light duty vehicles account for 20 mb/d. Displacement of conventional vehicles by PEVs or ZEVs reduces the largest segment of oil use.

As part of their work, U.S. EPA and ORNL also assessed the economic value represented by PEVs displacing oil imports. Their evaluation focused on the monopsonistic effect and macroeconomic disruption. A monopsonist is a sole or large demander of a commodity and, as such, the purchasing patterns of a monopsonist can directly impact pricing for all buyers. If the United States were to demand less oil, the world price of oil would likely decrease. The effect would be a net benefit to the U.S. economy, as those entities that purchase oil would be doing so at a lower

price. EPA and ORL modeled the monopsony effect that could be realized for each electric vehicle that substitutes oil import demand (Figure 25). For a PHEV20, PHEV40, and EV100, the net energy security benefits to the U.S. economy in 2025 would be \$523, \$729, and \$1,060 in 2013 dollars, respectively, over the life of the vehicle. EPA and ORL also modeled the macroeconomic disruption value. As part of their analysis they estimated the likelihood of future oil supply disruptions, the impacts of these types of disruptions to the U.S. economy, and ultimately how these types of costs would change U.S. consumption or import levels. The authors then quantified the dollar value of increased U.S. energy security for the avoided risk of macroeconomic disruption, per PEV. The combined economic benefit to the U.S. economy of monopsony and macroeconomic disruption is approximately \$1,000–2,000 per vehicle.

Vehicle Type	Monopsony (\$/vehicle)	Macroeconomic Disruption (\$/vehicle)	Total (\$/vehicle)
PHEV20	\$523	\$482	\$1,006
	(\$178 - \$1004)	(\$239 - \$769)	(\$579 - \$1497)
PHEV40	\$729	\$672	\$1,402
	(\$248 - \$1400)	(\$334 - \$1072)	(\$807 - \$2087)
EV100	\$1,060	\$978	\$2,040
	(\$361 - \$2037)	(\$486 - \$1560)	(\$1174 - \$3036)

**Figure 25: Energy Security Benefits in 2025 (in 2013 dollars)
(Undiscounted lifetime fuel savings)**

Source: (Leiby, 2014)

2.8 GREENHOUSE GAS BENEFITS OF PEVS

GHG emissions from driving PEVs vary depending on the electric grid used to charge the vehicle. There are also variations based on time of year, when resources such as solar and hydro may be in high or low production, and the time of day that vehicles are charged. Charging during peak electricity demand, during the day, is most often powered by natural gas and other fossil fuels, while nighttime charging will generally use lower-carbon sources such as wind and hydro. Many regions use electricity-pricing structures as incentives, including time of use pricing, to encourage distributing the electricity demand throughout the day and reduce the need for peak power production, which typically are fossil fuel intensive. Research evaluating Demand Response Management strategies indicates that pricing strategies can shift behavior of home PEV charging to off-peak, and typically lower-carbon, periods between midnight and 5:00 A.M. (Kurani et al., 2013). The studies presented in this section consider average annual electricity generation to determine GHG intensity.

The resource portfolio of different regional grids has a significant impact on the GHG emissions from the use of PEVs. In “State of Charge,” (Anair and Mahmassani, 2012) the Union of Concerned Scientists calculated the GHG intensity mpg equivalent (the equivalent mpg of an average gas-powered vehicle that produces the same emissions as a PEV on a mile-to-mile basis) of different power sources shown in Table 16, below. For example, powering a PEV on electricity produced from 100% coal is equivalent to a gas-powered vehicle getting 30 mpg, whereas electricity produced by solar is equivalent to 500 mpg. In areas where the power grid is composed mainly of fossil fuels, the GHG impact of driving PEVs is higher, and where there are more renewable resources, the GHG impact of driving PEVs is lower. Additionally, as renewable resources replace fossil fuel power plants through Renewable Performance Standards, electricity as a PEV fuel will become less carbon intense. It is important to note that these equivalencies reflect only the use of PEVs (the operations stage) and do not account for embodied emissions from manufacturing.

Table 16: Electricity source by Well-to-Wheels EV Miles Per Gallon Equivalent

Electricity source	Well-To-Wheels EV Miles Per Gallon Equivalent (mpg _{ghg})
Coal	30
Oil	32
Natural Gas	54
Solar	500
Nuclear	2,000
Wind	3,900
Hydro	5,800
Geothermal	7,600

Notes:

1. EV efficiency is assumed to be 0.34 kWh/mile, reflective of the Nissan LEAF, a five-passenger EV.
2. Production and consumption of gasoline are assumed to produce 11,200 grams CO_{2e}/gallon, based on GREET 1_2011 default values.

“State of Charge” also grouped grid regions according to their mpg equivalent and ranked them “Good” for mpg equivalents between 31 and 40, “Better” for mpg equivalents between 41 and 50, and “Best” for those regions with electric grids that have mpg equivalents above 51 (Table 17). Those regional rankings are displayed on the map below (Figure 26) along with the region’s average mpg equivalent.

Table 17: Global warming emissions rating scale for electric vehicles

Description	Good	Better	Best
mpg of a gasoline vehicle with equivalent global warming emissions	31–40 mpg	41–50 mpg	51+ mpg
Percent reduction in global warming emissions compared with 27 mpg gasoline vehicle	11–33%	33–46%	>46%

Notes:

1. Assumes 11,200 grams of global warming pollution per gallon of gasoline and EV efficiency of 0.34 kWh/mile, equivalent to the efficiency of the Nissan LEAF battery-electric vehicle.
2. Model year 2012 combined city/highway fuel economy window-label value. Data from (Fuel Economy Guide, 2012). All vehicles given as examples are classified by the EPA as midsize or smaller and have automatic transmissions so as to ensure a comparison consistent with the selection of electric vehicle efficiency assumptions. Rating scale is not appropriate for pickup trucks or other large vehicles.

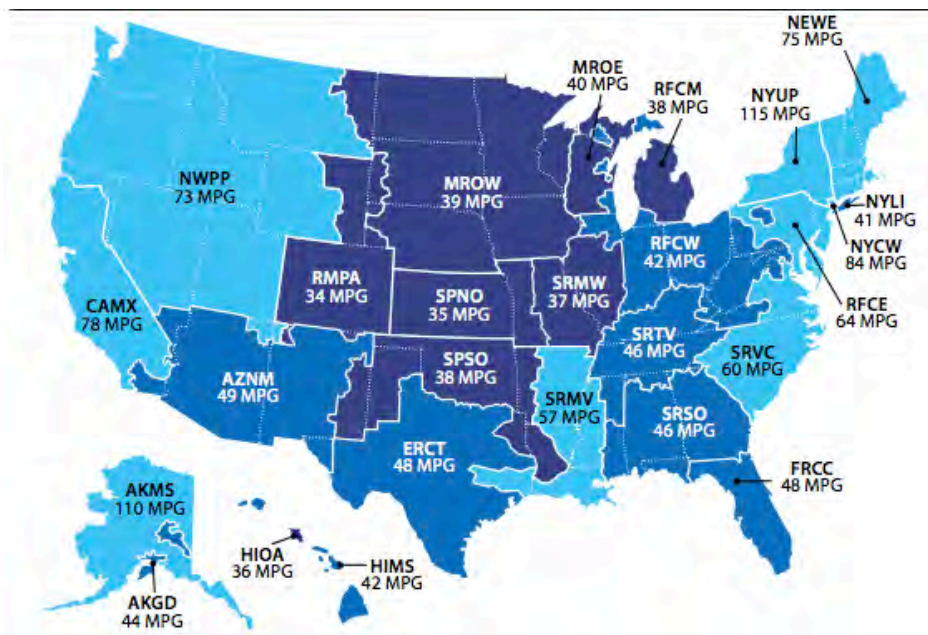


Figure 26: PEV charging on the current electricity grid by subregion

Source: (Union of Concerned Scientists, 2012)

The map depicts the mpg equivalency that a gasoline powered ICE vehicle would need to achieve to have comparable GHG emissions (CO₂e) to a PEV that is powered from the electricity grid in a particular subregion. Subregion carbon intensity varies depending on the generation

resource mix of that particular subregion. The lower the carbon intensity of the grid mix, the higher the mpg equivalent for comparable air emissions.

Notably, 83% of the U.S. population lives in areas where driving a PEV produces significant GHG reductions over the average gas vehicle, or is comparable to the highest efficiency gas vehicles (including hybrids). 45% of the U.S. population lives in regions that ranked “Best,” or regions where there is no gas-powered vehicle as efficient to drive as a PEV.

Additionally, the major PEV sales markets are primarily located in regions with lower GHG intense grids. The top five cities for overall EV sales are listed in Table 18, below, along with the corresponding region’s mpg equivalent. The top 15 Nissan LEAF markets are listed in Table 19, also with corresponding mpg equivalent.

Table 18: Top five cities for overall EV sales, along with the corresponding region’s mpg equivalent

Overall EV Market	Market Share (Seattle Times, 2013)	mpg Equivalent of Regional Grid (Union of Concerned Scientists, 2012)	Ranking (Union of Concerned Scientists, 2012)
San Francisco	19.5%	78	Best
Los Angeles	15.4%	78	Best
Seattle	8%	73	Best
New York	4.6%	84	Best
Atlanta	4.4%	46	Better

Table 19: Top 15 Nissan LEAF markets, along with the corresponding region's mpg equivalent

Nissan LEAF Top Markets (NISSAN, 2013)	mpg Equivalent of Regional Grid (Union of Concerned Scientists, 2012)	Ranking (Union of Concerned Scientists, 2012)
1. San Francisco-Oakland-San Jose	78	Best
2. Los Angeles	78	Best
3. Atlanta	46	Better
4. Seattle-Tacoma	73	Best
5. Portland, OR	73	Best
6. Honolulu	36	Good
7. San Diego	78	Best
8. Sacramento	78	Best
9. Nashville	46	Better
10. St. Louis	37	Good
11. Chicago	42	Better
12. Denver	34	Good
13. Washington, DC	64	Best
14. Dallas-Ft. Worth	48	Better
15. New York	84	Best

Climate Central performed another study, “A Roadmap to Climate-Friendly Cars: 2013,” (Yawitz et al., 2013) using the Nissan LEAF and the Toyota Prius as the main points of comparison, noting that PEVs are more climate friendly than the average new vehicle efficiency (at 25 mpg) in all states (Yawitz et al., 2013)¹³. GHG emissions for vehicle ownership are the sum of the embodied emissions from vehicle manufacture, the fuel used to operate the vehicle and the end of life disposal of the vehicle. Climate Central found that based on today's grid mix, the highly efficient Prius outperforms the all-electric LEAF when considering the emissions from manufacture in addition to driving emissions; there are only 13 states where the LEAF is more climate friendly than the Prius. The map shown below in Figure 27 shows in dark green those states that have lower GHG emissions per mile for the LEAF even when including manufacture, and in light green those states that have lower GHGs if manufacturing emissions are not considered. The key finding in this study is that the manufacture of the PEV battery produces many more GHGs than the manufacture of an internal combustion engine, and that produces a

¹³ Pg. 5

“carbon debt” that the lower GHG fuel must then pay back throughout the operation of the vehicle. It is important to note that this study does not take into account any battery recycling at the end of life that may help reduce some of that initial manufacturing impact over the complete life cycle of the vehicle.

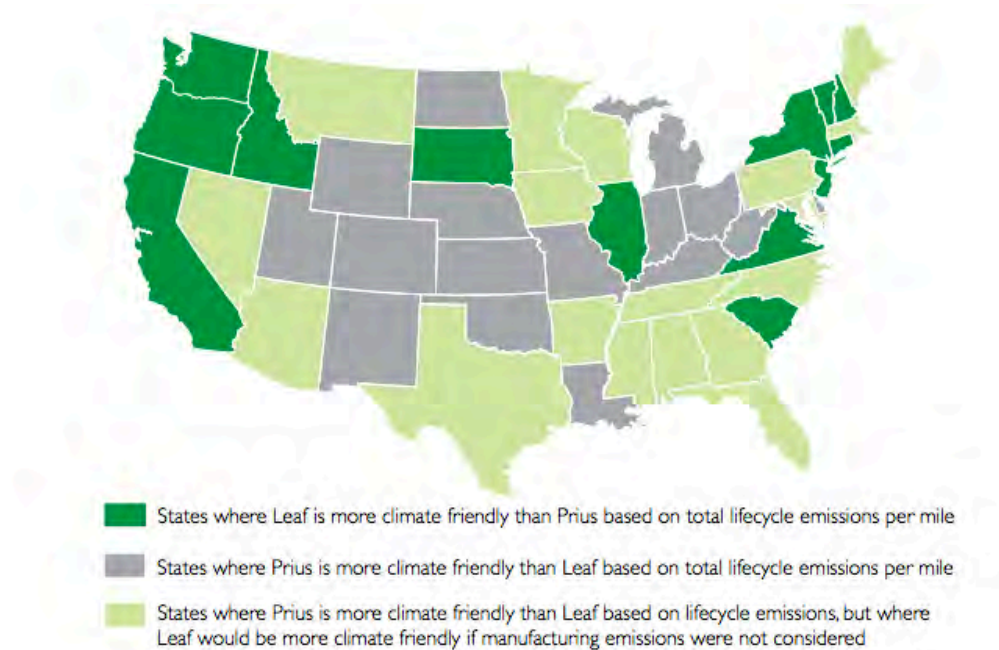


Figure 27: Representation of the 13 states where the electric LEAF is more climate friendly than the gas-powered Prius

Source: (Climate Central, 2012)

Both of these studies show the climate impact of PEVs based on today’s electrical grid and do not account for future reductions in the carbon intensity of electricity. Currently, 30 states and the District of Columbia (EIA, 2012) have implemented a Renewable Portfolio Standard (RPS) that requires minimum percentages of renewable electricity generation. The Energy Information Administration estimates that these efforts will reduce the emissions intensity of the U.S. average electric grid by 4.5% by 2020 (EIA, 2013a)¹⁴. Based on current trends, this reduction may come faster than EIA predicts. Climate Central reports that the carbon intensity of the U.S. grid has decreased by 8% between 2010 and 2012 (see below).

¹⁴ Total electric power consumption from EIA AEO 2013 “Energy Consumption by Sector and Source, United States, Reference Case”. Total emissions from electric power from EIA AEO 2013 “Energy-Related Carbon Dioxide Emissions by Sector and Source, United States, Reference Case.”

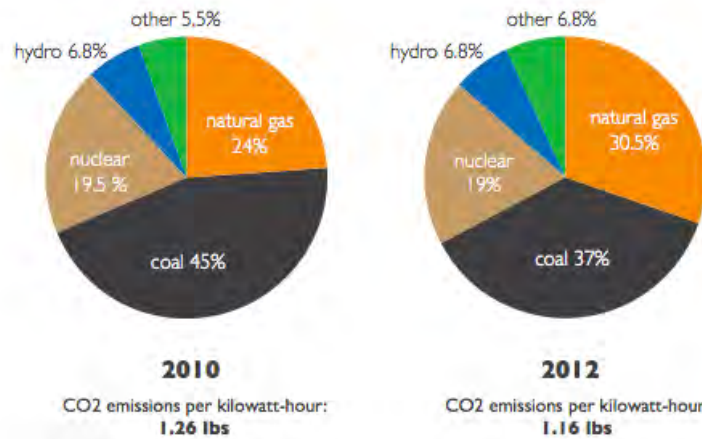


Figure 28: Decreasing Coal Power Since 2010 Reduced Emissions from Electricity

Source: (Climate Central, 2012)

The decrease in carbon intensity from 2010 to 2012 has tipped the scale for the environmental benefit of PEVs in multiple states, as shown in Figure 29, below.

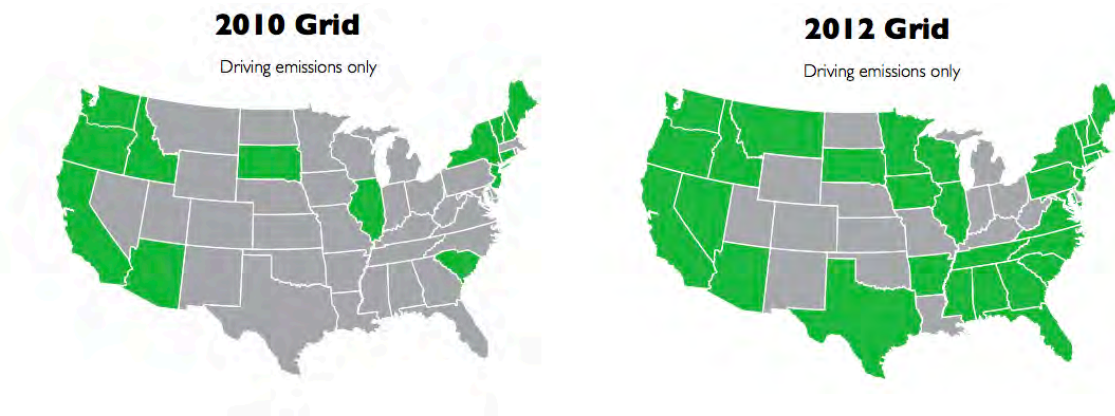


Figure 29: Environmental benefit of PEVs in the 2010 grid compared to the 2012 grid

Source: (Climate Central, 2012)

2.9 POLICY CONTEXT

Some policies may act as barriers to PEV adoption while other policies directly or indirectly incentivize PEV adoption. Two notable examples of policy challenges are local building permit laws and (at the state and local levels) the limitations on who can retail electricity (state level). Policies that indirectly encourage the market for PEVs include fuel efficiency standards and air pollution reduction regulations. Policies directly incentivizing PEVs include tax incentives, fuel economy mandates, zero emission vehicle (ZEV) regulations (for example California’s ZEV mandate), and preferred access to high occupancy vehicle lanes and preferred parking. In some cases, the leadership of state and local agencies is initiating the shift to support of PEVs, through

goal setting, which enables reporting agencies to develop policies and programs to encourage deployment. One such example is California's Governor Brown announcing in June 2014, the importance of electric vehicles to the state's GHG policy efforts and the effort to align the economy of "way of life" and "demands of nature." Governor Brown announced a goal of 1.5 million electric cars in California by 2025 (New York Times, 2014).

2.9.1 Potential policy, regulatory, and statutory challenges to PEV deployment

2.9.1.1 Interstate system right-of-way rules

When considering charging on the ROW, just a few codes and acts determine what is and is not allowed. The first of these codes is Title 23 of the U.S. Code, which addresses highways. Subsection 111 (23 USC 111) prohibits automotive service stations and commercial establishments from being constructed in the ROW of the Interstate system. This includes commercial charging stations. During the expert interviews several experts suggested that the prohibition of commercial charging stations on the Interstate ROW should be revised.

The second relevant act is the Moving Ahead for Progress in the 21st Century Act, which was signed into law in July 2012, and is known as MAP-21. MAP-21 creates opportunities for federally financed PEV charging infrastructure at fringe or corridor parking facilities with Surface Transportation Program (STP) funds or at other locations with Congestion Mitigation and Air Quality (CMAQ) funds.

The third rule that is relevant as an exception to the above code and act, the Interstate Service Area Rule, exists on toll roads which are part of the Interstate Highway system (such as the Pennsylvania Turnpike) and former toll roads that retain grandfathered service plaza agreements (such as I-95 in Connecticut). These highways, located mainly in the Northeast, may offer excellent venues for charging stations. Installations of Level 2 and DC Fast charging stations have already been funded for all the service areas on the Pennsylvania Turnpike.

2.9.1.2 Third-party right to sell electricity

Regulations in many states require that companies that sell or resell electricity are classified as utilities and fall under the authority of the states' public utilities commissions. This creates difficulties for businesses that want to develop onsite public, fee-for-service charging stations for use by their customers or employees. This issue is being resolved on a state-by-state basis, and may, in some states, require state legislative action. Several states, including California, Connecticut, Maryland, Michigan, Oregon and Connecticut have significantly researched the legal and regulatory issues associated with plug-in vehicles including resale of power by the third party (FHWA, 2012). In California, for example, the state ruled that electric vehicle service providers (EVSPs) are not public utilities and will not be regulated by the state public utilities commission. These EVSPs may operate any type of charging service and set their own pricing model and rates (MEC Intelligence, 2011). Maryland has taken a different approach, and has enacted state legislation explicitly excluding charging station providers from electric utility regulation (Charles Zhu and Nick Nigro, 2012).

A comprehensive state-by-state summary of EV-related laws and financial incentives can be found at DOE's Advanced Fuel Data Center website (Alternative Fuels Data Center, 2012).

2.9.1.3 Permitting and building codes

Prospective PEV owners must have home charging stations installed and permitted. The need for charging stations is considered a barrier to consumer adoption of PEVs.

The State of Oregon Building Codes Division recently adopted a rule that updates permitting and inspection criteria for charging stations. In an effort to keep pace with rapidly changing technology, this rule change establishes a single permit for charging system installations, rather than multiple permits for particular types of charging station electrical equipment (ETEC, 2010).

2.9.1.4 Highway funding

Motor fuel tax revenues are down in inflation-adjusted terms, with little prospect of rising in the short term, and they will continue to fall as conventional ICE vehicles become more fuel-efficient. A major shift away from ICE vehicles caused by increased adoption of PEVs would further accelerate the decline in gas tax revenues. Quantification of this effect is covered in Section 3.6.2, which also considers wider financial questions, including:

- The implications of replacing the lost revenue with charging income.
- The implications of replacing the lost revenue with a vehicle tax or a road user fee.

However, the need for maintaining and building transportation infrastructure continues.

The Highway Trust Fund and state gas taxes are not generating enough money to adequately fund surface transportation infrastructure, resulting in high costs to businesses and households (ASCE, 2011). Initiatives are therefore underway to introduce state-level road user fees (RUFs)

based on vehicle miles traveled rather than fuel consumption, for example by the State of Oregon (Oregon DOT, 2011, Oregon DOT, 2012). It has been argued that PEVs should also be included in such road user fees and contribute their fair share to highway maintenance.

There are several issues and barriers to road user fees, including privacy and environmental concerns. Most notably, vehicle mileage for individual vehicles would need to be centrally monitored, and the tax burden would shift from fuel consumption (and thereby carbon emissions) to motorized mobility more generally (Sean Slone, 2010). The need for gas tax reform was acknowledged during the expert interviews, but some of the experts argued that it was currently too early for a debate on the inclusion of PEVs. At worst, such a debate might send the wrong message and create another barrier to PEV adoption.

2.9.2 Indirect policy support for PEVs

2.9.2.1 Fuel efficiency standards

The National Highway Traffic Safety Administration (NHTSA) sets corporate average fuel economy (CAFE) standards for the fuel economy of passenger cars and light-duty trucks, and the U.S. Environmental Protection Agency (EPA) sets corresponding standards to limit emissions of GHGs from these vehicles. On August 28, 2012, President Obama finalized new fuel efficiency and GHG standards for passenger cars and light-duty trucks, requiring auto manufacturers to nearly double new vehicle average fuel economy to 54.5 miles per gallon by 2025 if achieved exclusively through fuel economy improvements. Both EPA and NHTSA believe that the new standards can be met primarily by improving technologies for conventional and hybrid vehicles. However, EPA's GHG standards include incentives that may increase the market share of EVs and PHEVs (and fuel cell vehicles). EPA sets a 0 gram/mi tailpipe compliance value for EVs and the electricity usage of PHEVs (up to per company sales caps in certain years). Additionally, every EV and PHEV sold in years 2017–2021 would count as more than one vehicle towards meeting compliance standards. The rule making documents are available from (EPA, 2014, NHTSA, 2014).

2.9.2.2 Low Carbon Fuel Standards/Renewable Portfolio Standards

A few states have adopted or are in the process of adopting a Low Carbon Fuel Standard (LCFS) or a Clean Fuel Standard (CFS). LCFS programs require fuel producers and importers to report the GHG emissions of the fuel they supply and reduce the GHG intensity of transportation fuels by a specific percent over time. Producers and importers can meet requirements in multiple ways, including by increasing the use of electricity as a transportation fuel.

Most states have Renewable Portfolio Standards (RPS). An RPS requires that a certain percentage of utilities' electricity retail sales be supplied from qualified renewable resources. The currency of compliance in the RPS is the Renewable Energy Certificate (REC), defined as the tradable commodity embodying the environmental benefits associated with a kilowatt hour of electricity generated by qualifying renewable sources.

As adoption of PEVs in a state with a RPS increases, the consumption of electricity will most likely increase as well. Thus, utilities will have to increase the amount of electricity provided from renewable resources in order to meet the RPS. Additionally, the environmental benefits of PEVs increase if they are charged with electricity from renewable resources.

2.9.2.3 Zero Emission Vehicle (ZEV) rules

Under the Clean Air Act, California is the only state that is allowed to adopt vehicle emission standards that are tighter than federal requirements. However, once California adopts such rules, other states may adopt the same rules if they do so *identically*. There are currently 11 other states that have adopted California's ZEV regulations: Arizona, Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, and Vermont.

California first adopted ZEV rules as part of its Low Emission Vehicle regulation in 1990, and they continue to be an important element in helping the state meet its GHG emission reduction goals. The objective of the ZEV rules is to make pollution-free vehicles available at a commercial scale as quickly as possible (California Environment Protection Agency, 2012).

California's ZEV rules require the largest auto manufacturers to earn increasing amounts of ZEV credits by providing the public with fuel cell vehicles, BEVs, PHEVs, or advanced hybrids. The auto manufacturers required to comply include BMW, Chrysler, Ford, General Motors, Honda, Hyundai, Kia, Mazda, Mercedes, Nissan, Toyota, and Volkswagen. The rules allow a great amount of flexibility, but in general, the farther a ZEV can travel without emitting pollution, the more ZEV credits it generates. Due to the flexibility allowing California to meet the requirements with various forms of vehicle technology, it is difficult to predict the precise number of vehicles and mix of technologies that will be deployed. Also, it is important to point out that in the short term, ZEV rules will not be a driver of EV sales; it is in the medium- to long-term where significant impact will be seen (California Environment Protection Agency, 2012). Yet on the production side, ZEV credits can represent a significant revenue driver for PEV manufacturers. ZEV credits and U.S. Corporate Average Fuel Efficiency credits represented \$194.4 million in income to Tesla, or approximately 9.7% of its annual revenue (Bloomberg, 2014).

California's Air Resource Board recently adopted amendments to strengthen and increase ZEV requirements in order to make sure the state was on track to meet its 2050 GHG emissions reduction goals. California's ZEV requirement has been extended through 2025 under California code 1962.2. By 2025, ZEV and PHEV sales should represent 15% of new vehicle sales (California Environment Protection Agency, 2012). Seven other states (Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont) have also adopted California's rules. The Pacific Coast Action Plan adopted in fall 2013 by British Columbia and the states of Washington, Oregon, and California will require by 2016 that one in every 10 government or business fleet vehicles will be a ZEV (Vancouver Sun, 2014).

Current projections reveal that only California and Oregon are on course to purchase sufficient numbers of ZEVs to meet the requirement in 2018 and 2019, yet not even California is anticipated to meet the requirement of ZEVs by 2022 (Navigant, 2014a).

One of the experts interviewed for the present study predicted that ZEV rules and similar policies are going to drive the participation of the large market players, specifically vehicle manufacturers, while another expert claimed that PEV sales are already relatively high and are actually outselling the ZEV mandates. The two views above illustrate the need for further research regarding whether ZEV rules are perceived to be functioning as a “carrot” or a “stick” and how this will change in future years as ZEV mandates increase.

2.9.3 Direct incentives for PEVs

2.9.3.1 Federal incentives

A federal tax credit is available for purchasers of PEVs. The incentive is funded through the American Recovery and Reinvestment Act of 2009 and is a \$2,500–\$7,500 tax credit, depending on the battery size (4–16 kWh), for electric-drive vehicles (EVs and PHEVs) sold after December 31, 2008. The tax credit applies to at least 200,000 units per vehicle manufacturer before it will begin to be phased out (Plug In America, 2012b, US Department of Energy, 2012b). In April 2014, U.S. Rep. Peter Welch of Vermont announced the Electric Vehicle Act legislation to increase the federal tax credit of PEVs and hybrids to \$10,000. According to Rep. Welch, the rationale is to increase the opportunity of middle-income households to afford a PEV (Green Fleet, 2014a).

The federal tax credit is the biggest financial incentive available to PEV-buying consumers in the United States and is considered a key instrument for encouraging the purchase of PEVs. Even with the tax credit, most PEVs currently have a higher initial cost compared to their ICE vehicle counterparts. Additionally, according to the Congressional Budget Office’s findings on the effects of the EV tax credit, in the near term it will have little or no impact on meeting CAFE Standards in terms of reductions in gasoline consumption and GHG emissions. However, in the long-term, if a revision to the CAFE Standards were to take place, the number of PEV sales could influence technological expectations and potentially result in a higher mpg requirement (CBO, 2012).

The federal tax credit and other available federal incentives intended to help deployment of EVs are described and summarized in Table 20 (CBO, 2012).

Table 20: Federal incentives to promote EV deployment compiled by the Congressional Budget Office

Incentive	Description	Budgetary Cost (Billions)
Tax Credits for New Plug-in Electric Drive Motor Vehicles	Tax credits of up to \$7,500 for buyers of new electric vehicles	\$2
Electric Drive Vehicle Battery and Component Manufacturing Initiative	Grants to manufacturers of batteries and other parts for electric vehicles	\$2
Transportation Electrification Initiative	Grants to establish development, demonstration, evaluation, and education projects to accelerate the introduction and use of electric vehicles	\$0.4
Advanced Technology Vehicles Manufacturing Program	Up to \$25 billion in direct loans to manufacturers of automobiles and automobile parts to promote the production of high-fuel-efficiency vehicles	\$3.1

During the EV forum, some participants expressed the opinion that a rebate on PEVs would be more attractive than a tax credit, because the latter doesn't have value for public agencies, and the former may also be psychologically more attractive to consumers.

2.9.3.2 State and local incentives

State financial incentives: More than a dozen states provide financial incentives, typically tax credits, in addition to the federal incentives for consumers who purchase electric vehicles. (NCSL, 2011) provides a list of monetary incentives for both EVs and charging station by state. Navigant Research performed a state-by-state analysis of electric car cost of ownership assessing state incentives and electricity prices. According to the analysis, Indiana PEV drivers experience the earliest payback on their purchase, with paybacks ranging from four to eight years (Navigant, 2014b).

State and local incentives are a significant driver; however, based on a University of Texas at Austin and Parsons Brinkerhoff study, technological innovations (e.g., increased driving range) and pricing influences (increased gasoline prices) have greater impact on PEV adoption, utilization, energy consumption and GHG emissions than incentive-based approaches such as free access to high occupancy vehicle lanes (described below) (Paleti et al., 2013).

In June 2014, eight states – California, Connecticut, Maryland, Massachusetts, New York, Oregon, Rhode Island, and Vermont announced a “Multi-State ZEV Action Plan,” that will

promote key actions such as incentives and support for fueling infrastructure, private fleet encouragement, signage, and workplace charging. The plan's goal is to assist the deployment of 3.3 million ZEVs by 2025 (C2ES, 2014a).

High occupancy vehicle (HOV) lanes: In areas traditionally plagued with dense traffic, HOV lanes—also known as carpool lanes—have proven a successful strategy in decreasing the number of single occupancy vehicles (SOV) on the road. Several states recognize the potential of encouraging EV adoption by allowing SOV EV drivers to use HOV lanes to reach their destinations. These states include Arizona, California, Florida, Georgia, Illinois, Maryland, New Jersey, New York, Tennessee, Utah, and Virginia (NCSL, 2011).

Other state incentives: Arizona allows alternative fuel vehicles to park in areas designated for carpools. Multiple states allow emission test exemptions for alternative fuel vehicles (NCSL, 2011).

During the EV Forum, several participants pointed out that preferential parking has received little interest from counties and municipalities. PEVs tend to be owned by wealthier citizens, and offering them preferential parking may cause public relations issues.

3 DEVELOPMENT AND ANALYSIS OF PEV DEPLOYMENT SCENARIOS

3.1 BACKGROUND

PEV deployment and infrastructure needs are currently modest with PEV sales of approximately 50,000 vehicles in the United States in 2012. Future implications of PEV deployment depend on how many PEVs will be on U.S. roads, their type, usage patterns, rate of adoption, and other factors.

The view from the expert interviews was that the future deployment of PEVs is hard to predict. Some opinions regarding future deployment include an expected increase in PHEV and REEV popularity and limited BEV adoption due to battery range concerns. Alternatively, ICE fuel efficiency improvements may make it difficult for all PEVs to compete.

This section reviews predicted levels of future PEV deployment from published literature, and refines them using information from interviews with experts and panel members. Some insights are also provided into the conditions that will favor particular types of PEVs and their usage. In addition to vehicles, the expected future deployment of charging stations is also considered.

3.1.1 Vehicles

3.1.1.1 *Current light vehicle fleet size and sales*

New light vehicle sales figures and the size of the whole light vehicle fleet in the United States are given to provide the context for projected numbers of PEV sales, and the fraction of the fleet represented. These values vary slightly according to their source and the definitions used. The Transportation Energy Data Book Edition 31 (Davis et al, 2012) reports that the total light duty fleet size is 130.9 million cars and 99.6 million light trucks (230.4 million total light vehicles) at the end of 2011. This total is close to the 223.8 million total light vehicle stock reported in the U.S. Annual Energy Outlook (AEO) 2013. In addition to data for 2011 and 2012, the U.S. AEO 2013 report predicts that by 2040, there will be 174.1 million light cars and 109.3 million light trucks. (These figures represent a 35% growth in cars and 15% growth in light truck stock in the next 27 years.)

The AEO 2013 projected fleet numbers are used as the foundation for the total light vehicle fleet projections in the scenario development and subsequent tasks of this project.

6,089,000 cars and 6,645,000 light trucks were sold in 2011 (12.734 million light duty vehicles), representing 5.53% of the light vehicle fleet. A detailed analysis of the age profile gives the average car lifetime as 16.9 years, and the average light truck lifetime of 15.5 years. These details become important when considering the rate of penetration of new vehicles into the fleet as a whole.

PEV sales are currently in their infancy. Data for 2011 and 2012 are given in Table 21 with the principal models sold.

Table 21: 2011 and 2012 sales figures for PEVs (Autoblog Green, 2013)

	Sales in 2011	Sales in 2012	Sales in 2013 ¹⁵	Description
Total PEV sales	17,500 0.29% new car sales 0.14% new light vehicle sales	50,000 0.82% new car sales 0.39% new light vehicle sales	95,000 1.25% new car sales 0.61% new light vehicle sales	
Nissan LEAF	9,674	9,819	22,610	BEV – compact hatchback
Chevrolet Volt	7,641	23,461	23,094	REEV – compact hatchback
Toyota Prius PHEV	0	12,750	12,088	PHEV – mid-sized hatchback
Ford C-Max Energi	0	2,384	7,154	PHEV – compact hatchback
Mitsubishi iMiEV	80	588	1,029	BEV – sub-compact
Tesla Model S	0	Estimated 2,500 (InsideEVs, 2012)	17,650	BEV – sports sedan

The data indicate that sales of PEVs are increasing rapidly, and data shows that this increase extended into 2013 with a 90% increase in sales relative to 2012. The data also illustrates the impact of new models becoming available (the Toyota and Ford PHEVs in 2012). In late 2012, the Tesla S (a four-door fastback sports sedan BEV) became available, and this is also expected to increase sales of BEVs.

3.1.1.2 Evolution of vehicle sales

As noted in Table 21, sales of PEVs are increasing. However, the relatively limited choice of models available will distort the sales figures, particularly the ratio of pure BEV vehicles to those including a gasoline engine.

U.S. DOE reported that the estimated cumulative U.S. supply of electric vehicles from 2011 through to 2015 will exceed 1,000,000 vehicles (US Department of Energy, 2009). Most of this analysis is summarized in Table 22. However, on May 1, 2013, EV car maker Fisker filed for

¹⁵ Data for 2013 taken from <http://evobsession.com/electric-car-sales-increased-228-88-2013/>

bankruptcy protection. Therefore, the 231,000 cumulative total sales of the Karma and Nina PHEV models that were included in DOE's original assessment have been removed, reducing the cumulative sales total through 2015 to a value slightly less than 1,000,000 vehicles.

Table 22: Estimated U.S. supply of electric vehicles between 2011 and 2015

Manufacturer and model	2011	2012	2013	2014	2015	Total
Ford Focus EV	-	10,000	20,000	20,000	20,000	70,000
Ford Transit Connect EV	400	800	1,000	1,000	1,000	4,200
GM Chevrolet Volt	15,000	120,000	120,000	120,000	120,000	505,000
Navistar eStar EV (truck)	200	800	1,000	1,000	1,000	4,000
Nissan LEAF EV	25,000	25,000	50,000	100,000	100,000	300,000
Smith Electric Vehicles Newton EV (truck)	1,000	1,000	1,000	1,000	1,000	5,000
Tesla Motors Model S EV	-	5,000	10,000	20,000	20,000	55,000
Tesla Motors Roadster EV	1,000	-	-	-	-	1,000
Think City EV	2,000	5,000	10,000	20,000	20,000	57,000
Cumulative Total	44,600	167,600	213,000	283,000	283,000	991,200

Note: The above numbers have been taken from announced production figures and media reports. In some cases, more conservative estimates have been used due to delays that have occurred since figures were announced.

Major auto manufacturers such as Chrysler, Honda, Mitsubishi, Hyundai, Toyota, Volkswagen, and Volvo are not included in the DOE statistics. However, these companies have announced, or are expected to announce, the introduction of PEVs in this time period. Additionally, the experts preparing this report note that the numbers for the Volt and LEAF look aggressive, and may be overly optimistic, at least during the current economic slump.

The above projections strongly suggest that the market supply should be available to meet the aspirational target of one million electric vehicles on the road by 2015. However, forecasts for PEV market growth over the next decade vary widely, and diverge even more for the 2020–2050 timeframe. The expert interviews characterized the future deployment of PEVs as being difficult to predict. The EV forum participants agreed with this view.

Table 23 summarizes a number of forecasts, including a fleet deployment of 250,000–500,000 vehicles by 2015, increasing to 1–4 million PEVs by 2020, then increasing again to 5–30 million by 2030.

These analyses probably underestimate the potential of significant policy interventions. Given strong political will, it is possible to achieve one million PEVs in the fleet by 2015. However, at the time of writing, this does not appear likely because sales in 2011, 2012, and 2013 were just 17,500, 50,000 and 95,000, respectively, making cumulative sales of PEVs from January 2011 to

December 2013 approximately 162,500 vehicles. To achieve a cumulative fleet number of 1 million by 2015 would require the sale of almost 837,500 PEVs in 2014 and 2015, representing a massive uptick from current sales.

If consumers' experiences are favorable, then the higher levels of PEV penetration could possibly be reached by 2030.

Table 23: Forecasts of the fleet population of PEVs from a range of sources

Forecaster	Prediction	Year	Notes
Pike Research (Pike Research, 2011)	1.0 M	2017	-
CAR 2010 (Center for Automotive Research, 2011a)	0.47 M	2015	-
Zpryme (Zpryme, 2010)	0.73 M	2016	-
DOE Annual Energy outlook 2013 (EIA 2013)	0.91 M 3.32 M (1.27% of all LDV) 6.32 M (2.23% of all LDV)	2020 2030 2040	Used as Scenario 1
MIT 2007 (MIT, 2007)	17.3 M (7.5% of all LDV, 230 M)	2035	-
National Academy of Science (National Academy of Sciences, 2010)	Approx. 1 M 13 M 100 M	2020 2030 2050	Probable penetration
Berkley, 2009 (Center for Entrepreneurship & Technology University of California, 2009)	0.8–3.2 M 8–21 M 65–100 M 180–240 M	2015 2020 2030 2050	See paragraph following the table
EPRI (2012 COG EV Taskforce presentation)	0.8–3.2 M 2.5–8 M 12.5–50 M	2015 2020 2030	See explanation below and Figure 30 and Figure 31.
IEA Technology roadmap (European Green Cars Initiative, 2010)	50% of light duty sales, i.e., fleet of approximately 100 M	2050	-

The Center for Entrepreneurship and Technology (Berkeley) estimated the rate of market adoption of PEVs in the United States to 2030. It used a network externalities model that accounts for the purchase price and operating costs of PEVs using switchable batteries and charging networks financed by pay-per-mile contracts. The baseline forecast is that by 2030, PEVs will account for 64% of light vehicle sales and 24% of the U.S. light vehicle fleet. Given the average age of light vehicles at approximately 16 years, these baseline sales figures (the lower end of the range given) translate into slightly more than 64% of the U.S. light vehicle fleet being PEVs by 2050.

The Center for Solar Energy and Hydrogen Research Baden-Württemberg released a PEV market analysis in April 2014 stating that the number of PEVs had quadrupled over the prior two years to more than 400,000, with nearly half sold in the United States. If sales trends continue at the same pace, more than 1 million electric vehicles will be on the road by early 2016 (E&E Publishing, 2014).

Two other scenarios considered the effect of high oil prices (as defined in EIA's AEO 2009) and high oil prices plus subsidies for the signing of long-term per-mile-contracts. These scenarios project maximum market shares up from 64% in 2030, to 85% (high oil prices) and 86% (high oil prices plus subsidies) of the light duty vehicle sales.

The EPRI projections are taken from a presentation given by the Council of Governments (COG) EV Task Force in October 2012 (COG EV Task Force, 2012) and reproduced in Figure 30 and Figure 31.

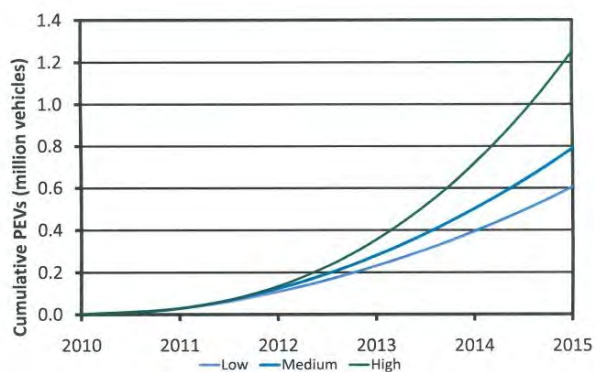


Figure 30: PEV Projections through 2015, from EPRI 2012 study

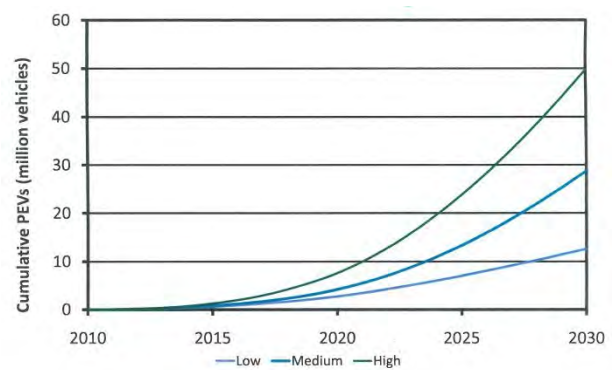


Figure 31: PEV Projections through 2030, from EPRI Study

Other factors that will drive increased adoption of PEVs include the upfront costs and operational costs, overall lifetime cost of ownership, the image of EV ownership by consumers, and the availability of the desired vehicles. External factors like the cost of the alternatives—i.e., gasoline—will also be important.

3.1.1.3 Where the vehicles will be sold

Table 24 and Table 25 show PEV market share and fleet penetration rate estimates by state and point in time. Figure 32 shows projected PEV numbers in selected states out to 2030.

Table 24: PEV market share by state and point in time

State/District	2015 PEV Market Share (% of new vehicle sales)	2020 PEV Market Share (% of new vehicle sales)	2025 PEV Market Share (% of new vehicle sales)	2030 PEV Market Share (% of new vehicle sales)
Washington	3.5	8.3	14.4	20.6
Oregon	3.7	8.6	14.8	21.0
California	4.0	9.1	15.4	21.7
Arizona	2.5	6.8	12.5	18.5
Texas	1.0	4.4	9.5	15.2
Tennessee	1.2	4.8	10.0	15.7
Washington, D.C.	4.8	10.4	17.0	23.4

Source: Electric Power Research Institute (EPRI, 2011).

Table 25: Fleet penetration rates by state and point in time

State/District	2015 PEV Penetration (% of vehicles in service)	2020 PEV Penetration (% of vehicles in service)	2025 PEV Penetration (% of vehicles in service)	2030 PEV Penetration (% of vehicles in service)
Washington	0.8	3.1	7.1	12.3
Oregon	0.9	3.3	7.3	12.5
California	1.0	3.3	7.3	12.4
Arizona	0.6	2.5	5.9	10.6
Texas	0.2	1.3	3.9	8.0
Tennessee	0.3	1.5	4.2	8.3
Washington, D.C.	1.2	4.1	8.8	14.6

Source: Electric Power Research Institute (EPRI, 2011).

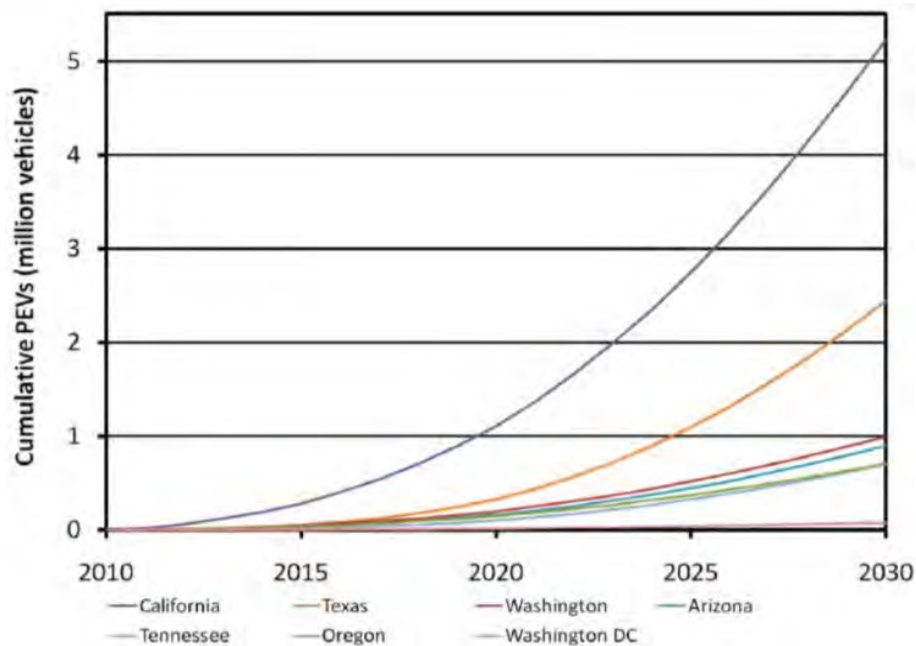


Figure 32: Graph of projected PEV numbers in selected states to 2030

Source: Electric Power Research Institute (EPRI, 2011).

Pike Research conducted a study looking at population, economics, and demographics of current hybrid vehicle owners, as well as survey data from an electric vehicle consumer survey and manufacturer vehicle rollout schedules. The study projects that the following states are expected to lead the way as measured by cumulative PEV sales between 2012 and 2020:

1. California with 443,000 cumulative vehicle sales and 4.5% of total new sales in 2020.
2. New York with 196,000 cumulative vehicle sales and 3.5% of total new sales in 2020.
3. Florida with 113,000 cumulative vehicle sales and 1.9% of total new sales in 2020.
4. Texas with 109,000 cumulative vehicle sales and 1.4% of total new sales in 2020.

Hawaii is expected to have the highest concentration of PEV vehicle sales, representing 12.3% of total vehicles sold in the state by 2020 (Pike Research, 2012b). This projection may indicate that a "captive fleet" makes it easier to develop charging station infrastructure.

The top five metropolitan statistical areas (MSAs) for PEV sales are expected to be (Pike Research, 2012b):

1. New York City, NY.
2. Los Angeles, CA.
3. San Francisco, CA.
4. Seattle, WA.
5. Portland, OR.

By 2020, these cities are expected to account for over 25% (or 109,000 vehicles) of all PEV sales in the United States (Pike Research, 2012a).

Another source of market forecasts is a series of Community Readiness Plans that have been submitted to the U.S. Department of Energy. Not all Community Readiness Plans contain market forecasts; some are relative. For example, in Oregon the forecast takes the form of a goal “to exceed the State’s per capita share of the national goal of one million PEVs by 2015.” Others give vehicle numbers; for example, New England estimates 100,000 EVs on the road in the Transport Construction Inspectors region by 2015. Still others give fleet percentages; for example, Colorado forecasts that up to 10.2% of the light duty fleet will be PEVs in 2025.

3.1.1.4 The fraction of the PEVs predicted to be BEVs

In addition to overall light fleet projections, the U.S. AEO 2013 provides projections for PEVs. These projections are categorized into 100- and 200-mile-range BEVs, and 10- and 40-mile-range PHEVs. They are also sub-divided into fleet numbers for cars and light trucks. From these projections, the fraction of all PEVs that are purely electric vehicles—i.e. the BEV/PEV ratio—can be calculated: 7% BEVs in 2020, 14.5% in 2030, and 23.5% in 2040.

The expert interviews included feedback that these ratios are reasonable. The EV Forum suggested that scenarios should be investigated including a 50:50 BEV/PHEV split.

3.1.2 Charging stations

Just as the expert interviews indicated that the future deployment numbers of PEVs are hard to predict, they also commented that “the future deployment of charging station infrastructure is also impossible to predict at this point in time”¹⁶.

Pike Research predicts that global charging station sales will steadily climb at a compound annual growth rate of 37% from 2012 to 2020 (Pike Research, 2012a), meaning that the approximately 200,000 charging station sold globally in 2012 will increase to 2.4 million stations sold in 2020 (Pike Research, 2012a). This estimate includes Level 1, Level 2, and DC Fast chargers, both publicly and privately owned. Figure 33 shows anticipated charging station sales worldwide by region in 2012–2020 (Pike Research, 2012a).

A recent report by Frost and Sullivan estimated a total of 4.1 million charging station units in North America by 2017. Level 1 charging stations for residential charging are anticipated to represent 71% of these units. Level 2 charging stations will represent 27% of installations, with DC Fast chargers only representing a sliver (2%) of installations. According to the study, home charging is expected to represent 87% of all EV charging (Autoblog Green, 2012).

¹⁶ Taken verbatim from Expert Interview Summary.

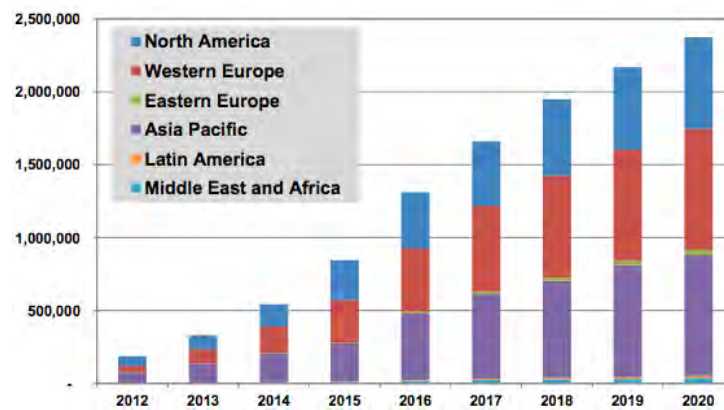


Figure 33: Pike Research graph depicting anticipated charging station sales by region worldwide

By 2020, Pike Research predicts that North American sales of charging points will reach 626,000 units for that year, compared to 66,000 units sold in 2012. This sales growth represents the largest charging station market globally. Similar to the PEV market, the charging station market in the United States will be mostly focused in a handful of states, with these concentrated installations accounting for about 50% of installations. These states include (Pike Research, 2012a):

1. California.
2. New York.
3. Florida.
4. Texas.
5. Washington.
6. Illinois.

At the high end, one expert predicts one million public chargers by 2015.

One expert interviewed for this study stated that *“The standard that works right now is Level 2. Level 2 has to be the basis of everything because all PEVs can use it. It is the safety network.”* Further discussion showed that this view did not mean DC Fast charging should not be added, but rather that the current lack of standardization of DC Fast charging points, and the fact that many vehicles are not equipped to use them, mean that DC Fast charging cannot currently be used exclusively as a safety network. The EV Forum discussions suggested that PEV drivers occupy one of two distinct camps: quick charging proponents who only want quick charging, and slow charging proponents who appreciate the advantages and challenges of all charging levels.

Another issue raised was the potential challenge of drivers waiting in line to charge their vehicles at charging stations. The possibility of using software to reserve a spot at a station in advance was raised, but the challenges of charging taking longer than the time duration booked, or vehicles not showing up at the times reserved, were pointed out. DC Fast charging would potentially alleviate these types of problems.

As part of its Clean Cities Program, U.S. DOE awarded \$8.5 million to 16 EV Community Readiness projects in September 2011. The projects span 24 states and the District of Columbia, and the grant recipients are shown in Figure 34. The purpose of the projects is to help communities prepare for EV deployment and charging infrastructure (Clean Cities, 2012). Grant recipients must prepare EV Community Readiness Plans, which contain regional EV and charging station deployment projections.



Figure 34: Clean Cities Community Readiness & Planning for PEVs and Charging Infrastructure

A summary of the activities, outputs and lessons for all sixteen readiness plans has been published by C2ES titled *A Guide to the Lessons Learned from the Clean Cities Community EV Readiness Projects*. While each published plan covers a broad spectrum of topics related to their regional context, several topics common to almost all of the published plans include:

- Barriers assessment.
- Policy evaluation/recommendations.
- Incentives.
- Education and outreach.
- Building codes, zoning and permitting.
- EVSE development.

Other topics covered by several of the plans include:

- Utilities.
- Fleet strategies.
- Signage.
- Compliance with American Disability Act (ADA) standards.

In addition to the topics listed above, most of the plans include a market assessment of existing conditions—i.e., how many PEVs are currently registered in the project area, and how many charging stations are installed. Several of the plans also forecast, estimate, or set goals for how many PEVs will exist in the project area in the future. A key lesson learnt from the activities is how partnerships with a wide range of stakeholders are essential for advancing PEV adoption. Some key barriers to PEV adoption were identified; much of the report discusses developing and implementing solutions to overcome these barriers. The vast majority of the themes covered are identified and discussed in this report, and further references to the C2ES report are included in later sections.

The *Albany Electric Vehicle Feasibility Study* examines the ways that Albany, New York City, and other cities can support and promote the use of EVs. The goal of the study is to “identify what actions must be taken to make a city EV ready.” Table 26 provides a checklist of actions the study compiled as important for EV readiness.

Table 26: Actions cities should take to be EV ready: A Checklist for EV Readiness

✓	Revise existing building code to remove barriers to installation of EV infrastructure
✓	Update zoning to allow for EV charging stations in all major zoning categories (differentiating between Levels I, II and DC by zoning category)
✓	Include standards in building code and permitting language for siting within historic and other speciality districts
✓	Integrate EV charging infrastructure considerations into design review process for new developments, including buildings, and especially for sidewalks, streets and parking areas
✓	Develop policy for siting EV charging infrastructure within residential districts where residences typically do not have garages
✓	Expedite permitting for EV charging stations
✓	Adopt standard design and visibility requirements for EV charging station signage
✓	Adopt standard policies on ownership and installation of EV charging stations on public property
✓	Work with local utility EARLY to determine capacity for increase in demand from EVs and to determine connection costs and processes
✓	Adopt a fine schedule for parking violations within EV designated parking spaces
✓	Establish fees associated with use of equipment on government property
✓	Adopt a policy/strategy for incorporating EVs into municipal fleet
✓	Form a stakeholder group within the community - businesses, institutions, local utilities, interested consumers, fleet operators to evaluate demand and create strategies for EV adoption
✓	Create an education and marketing program to educate the community about EVs, infrastructure, and available incentives
✓	Consider provision of free/ discounted tolls, parking, HOV lanes, and other driving incentives, including free or reduced price charging at certain times or locations
✓	Work with taxi fleets, rental car companies, and car-sharing programs to integrate EVs and charging infrastructure
✓	Work with colleges, technical schools, and other education providers to develop EV workforce training courses and programs
✓	Coordinate with fire, EMS, police, and other emergency responders to provide EV-specific training offered by the Fire Protection Research Foundation

Additionally, the Albany study determined what the utilization rates of charging stations might be over time as EV use increases. The study assumes that initial charging stations will be built with excess capacity beyond current demand needs and will therefore be underutilized at first. However, the study suggests this should be done intentionally to “promote the adoption of EVs through changed public perception” (VHB Engineering, Surveying and Landscape Architecture, P.C., 2012). The assumption is that once drivers feel more comfortable with the available charging infrastructure, they will be more likely to purchase PEVs. Over time, the ratio of charging stations to drivers is estimated to decrease, as shown in Table 27 (VHB Engineering, Surveying and Landscape Architecture, P.C., 2012).

Table 27: Public charging station demand ratios from the Albany Electric Vehicle Feasibility Study

Chargers per vehicle/year	2010	2020	2030
Expected Public Chargers per Vehicle	2.0	1.5	1.0
Maximum Public Chargers per Vehicle	2.5	2.0	1.5
Minimum Public Chargers per Vehicle	1.5	1.0	0.5

3.2 SUMMARY OF THE EIGHT PEV DEPLOYMENT SCENARIOS

Eight PEV deployment scenarios have been developed as part of this research and are presented in this report. They have been developed based on the over-arching principle that the scenarios must be credible. The scenarios describe eight plausible visions of PEV deployment in the United States in the future, ranging from conservative to very ambitious. The vehicle deployment numbers are bracketed by PEV populations that have been previously published as part of EIA’s Annual Energy Outlook (AEO) 2013 (EIA, 2013a) and also published by EPRI (COG EV Task Force, 2012) as its high-growth projection. These deployment numbers have been projected into the future as far as 2050.

All of the scenarios, however, can be viewed as incremental developments of the existing factors that influence deployment. None include what could be described as potentially game-changing phenomena that would accelerate growth of PEV sales and therefore the need for FHWA action. Such game-changing phenomena could include:

- Non-linear sales growth due to rapidly increasing demand. Since completion of the initial literature review, the number of PEVs sold in the United States in 2012–2013 jumped by approximately 84% to 96,600.
- Dramatic price reductions, either from improvement in range growth from battery development or from other production efficiencies.
- Dramatic improvement in charging technology (i.e., widespread inductive charging), ease, and cost.
- Extreme changes in fuel/charging type, availability, and price.

- Demographic and use pattern changes which could be caused by generational shifts associated with the “Internet generation” moving into the age of purchasing durable goods.
- Further regulatory changes rapidly driving up ICE fuel economy, reducing emissions and/or decreasing energy consumption (e.g., aggressive national GHG regulation, or CAFE standards raised significantly).
- Rapid adoption of Vehicle-to-Grid integration.
- Other yet unidentified disruptive technology.

While such game-changing phenomena are not included, their occurrence would be expected to accelerate the rate of deployment. The scenarios presented do encompass a wide range of uptake scenarios, with Scenario 8 having approximately a 50% PEV fleet composition by 2050. Because of the rate at which new vehicles penetrate the fleet, and the starting fleet composition, most of the game-changing effects noted above would, in the mid-term, lead to deployment numbers and charging patterns that are included within the scenarios analyzed; the only difference being that a particular deployment number would be reached sooner than the year shown in the deployment profiles of the scenarios analyzed.

The scenarios begin with the current PEV fleet numbers and describe potential PEV deployment and usage patterns for 2020, 2030, 2040, and 2050, specifying four parameters that are key inputs to this analysis of the implications. These parameters are:

- PEV uptake (specified in terms of the numbers of PEVs in the fleet for the analysis years).
- BEV/PEV ratio—i.e., the fraction of all the plug-in EVs that are electric only and do not have an integral internal combustion engine (ICE).
- Expected vehicle range for the BEVs.
- Location of sites where vehicles are being charged (the demand for future charging infrastructure needs).

Figure 35 shows the projected PEV adoption in terms of the numbers of PEVs in the fleet.

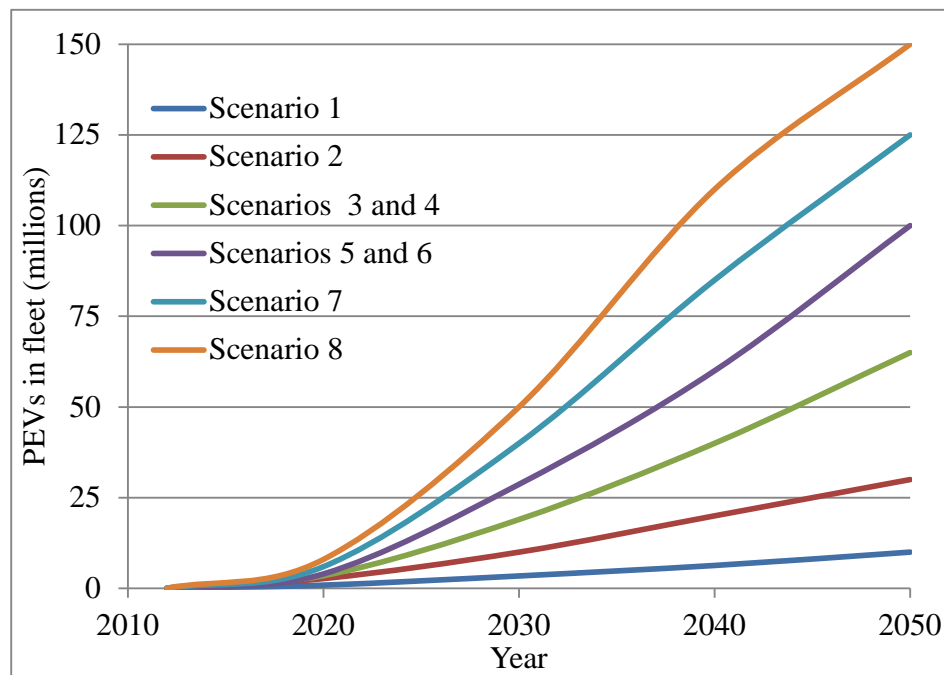


Figure 35: Projected PEV population by deployment scenario

The origins of the numbers used in the scenarios are:

- Scenario 1: Based on AEO 2013 reference case
- Scenarios 2, 3 and 4: PEV numbers developed for this research between Scenarios 1 and 5
- Scenarios 5 and 6: Based on EPRI “Medium” PEV growth projections
- Scenario 7: PEV numbers developed for this research between Scenarios 5 and 8
- Scenario 8: Based on EPRI “High” PEV growth projections

In terms of the important PEV or infrastructure characteristics, the assumptions underlying the scenarios are summarized below, along with their key differences. For example, from these descriptions, Scenario 4 is seen as investigating the impact of a higher demand on the non-residential charging infrastructure, with PEV numbers and fleet composition held constant. Similarly, Scenario 6 investigates the impact of large increases in the BEV fraction of the PEV fleet, and also an increase in their average range, with PEV numbers remaining constant. This scenario could arise if there was a significant change in battery technology or cost.

Table 28: Summary of important assumptions on PEV and infrastructure characteristics for the different scenarios

Scenario	PEV uptake as fraction of fleet	BEV to PHEV + REEV ratio	Average range of BEVs	Fraction of charging not at home (on Interstate)
Scenario 1	AEO 2013 reference case	AEO 2013 reference case	100 miles	5% (0.4%) 2030 & 5% (1.0%) 2050
Scenario 2	First step between Scenarios 1 & 5	AEO 2013 reference case	127 miles because of Tesla sales	5% (0.4%) 2030 & 5% (1.0%) 2050, i.e., as for Scenario 1
Scenario 3	Second step between Scenarios 1 & 5	25% for 2020 onwards	135 miles by 2030 & 150 miles by 2050	5% (0.8%) 2030 & 5% (2.0%) 2050 Interstate double that of Scenario 2
Scenario 4	Same as Scenario 3	25% for 2020 onwards	135 miles by 2030 & 150 miles by 2050	20% (8%) 2030 & 30% (15%) 2050 very high away from home
Scenario 5	EPRI Medium projection	25% for 2020 onwards	135 miles by 2030 & 150 miles by 2050	5% (0.8%) 2030 & 5% (2.0%) 2050 as for Scenario 3
Scenario 6	EPRI Medium projection	Increasing up to 70% in 2050	150 miles by 2030 & 180 miles by 2050	10% (1.0%) 2030 & 20% (3.0%) 2050 double away from home relative to Scenario 5
Scenario 7	Intermediate between EPRI Medium and High Scenarios	Increasing up to 70% in 2050	150 miles by 2030 & 180 miles by 2050	10% (1.0%) 2030 & 20% (3.0%) 2050 As for Scenario 6
Scenario 8	EPRI High growth projection	Increasing up to 70% in 2050	175 miles by 2030 & 220 miles by 2050	20% (8%) 2030 & 30% (15%) 2050 very high away from home

Figure 36 uses the PEV fleet numbers shown in Figure 35 and the identified BEV/PEV ratios to calculate the numbers of BEVs, PHEVs, and REEVs that comprise the PEV numbers. The proportion of BEVs increases with the increasing number of PEVs, and occupies a greater portion of total PEVs in Scenarios 6, 7, and 8 in later years. For example, in 2050, BEVs represent roughly 25 percent of all PEVs for Scenarios 1–5, compared to approximately 70 percent for Scenarios 6, 7, and 8. This difference is because PEV deployment is expected to increase as battery performance improves and costs decrease. This effect also leads to increasing BEV range and affects the charging infrastructure requirements.

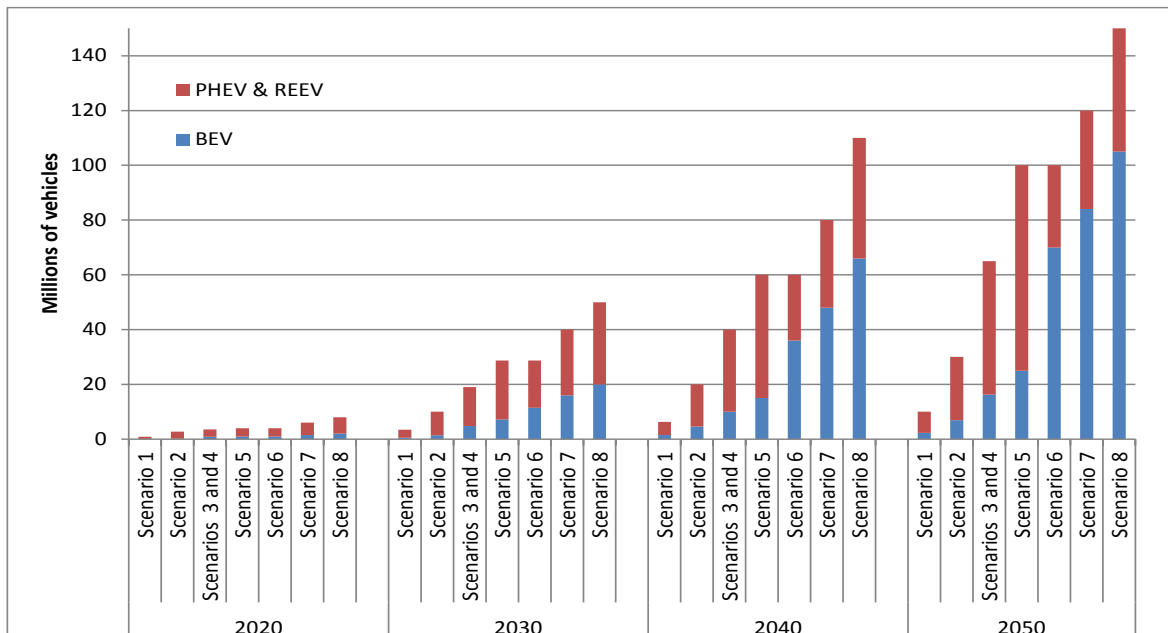


Figure 36: BEV and PHEV & REEV counts by scenario-year combination

Figure 37 shows the BEV fleet average ranges in the four target years, for each of the eight scenarios. For this parameter, increased PEV deployment is linked to increases in range. A noteworthy exception is the driving range data for Scenarios 2 and 3 for the year 2020, where the average BEV ranges are 127 miles and 120 miles respectively. Scenario 2 assumes more modest growth in BEV penetration than Scenario 3, but Scenario 2 includes a larger fraction of BEVs with a driving range of 300 miles (i.e., vehicles such as the Tesla Model S), which increases the overall average driving range for Scenario 2. While the market for such vehicles is small and somewhat atypical, the higher penetration rate of these vehicles in Scenario 2 means that the overall 2020 average driving range for this scenario is higher than for Scenario 3, even though the total penetration of BEVs in this year is assumed to be lower than for Scenario 3. However, the majority of BEVs in each of these scenarios only have a 100-mile range, lowering the average range for all BEVs.

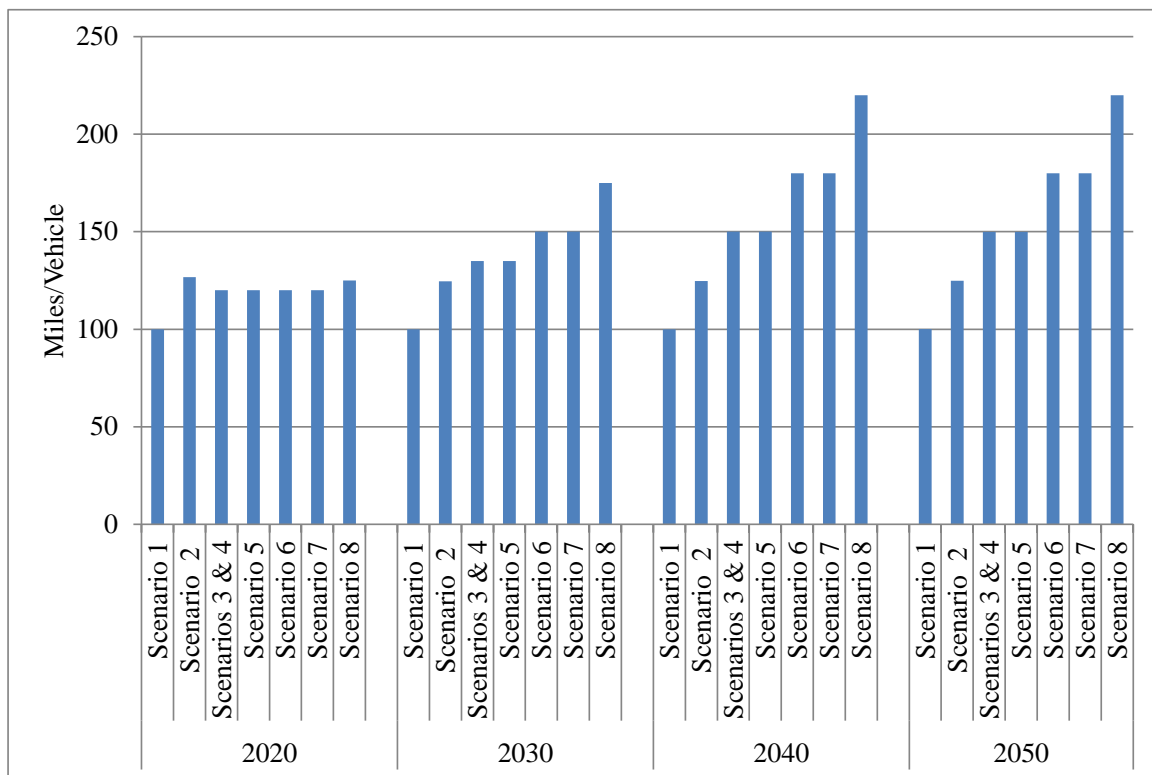


Figure 37: Projected electric-only driving ranges at full charge for the BEV vehicle fleet by scenario-year combination

When developing the scenarios, vehicle charging was presumed to occur in one of the following locations:

- At home or at work.
- At local destinations, using publicly accessible chargers.
- Mid-trip, using publicly accessible chargers on or near the Interstate right of way (ROW).

The amount of electric charge added at each of these types of locations was specified in the scenario definitions and is summarized later in Figure 52. Section 3.5.2 considers the implications of the various scenarios on publicly accessible charging infrastructure.

3.3 ANALYSIS METHODOLOGY

The analysis of the implications of the PEV deployment scenarios involves a combination of quantitative and qualitative analysis, and shown schematically in Figure 38.

The quantitative analysis uses the number of PEVs, percentage of BEVs in the PEV fleet, and the average BEV range (defined as outputs from the scenario development), to calculate the numbers of PEVs in each vehicle category (car/small truck, BEV/PHEV or REEV, and its electric range).

Based on industry and practitioner interview evidence and technical research, the research team made assumptions regarding the average annual mileage of each vehicle category using electric power, and the average electric charge required for each mile traveled, for each vehicle category. Based on these estimates, the electricity consumed by the PEV fleet can be calculated for each of the eight deployment scenarios, and for each target year (2020, 2030, 2040, and 2050).

In addition, the average volume of gasoline displaced for each kWh of electricity consumed is estimated, again based on vehicle performance assumptions. Based on this value, and on the amount of electricity consumed by the PEV fleet for each scenario-year combination, the research team calculates the total volume of gasoline displaced by electricity. The volume of displaced fuel is multiplied by the federal gas tax rate to determine the revenue lost to the Highway Trust Fund (HTF) for each scenario. The methodology assumes that the rate of tax per gallon remains constant in the future.

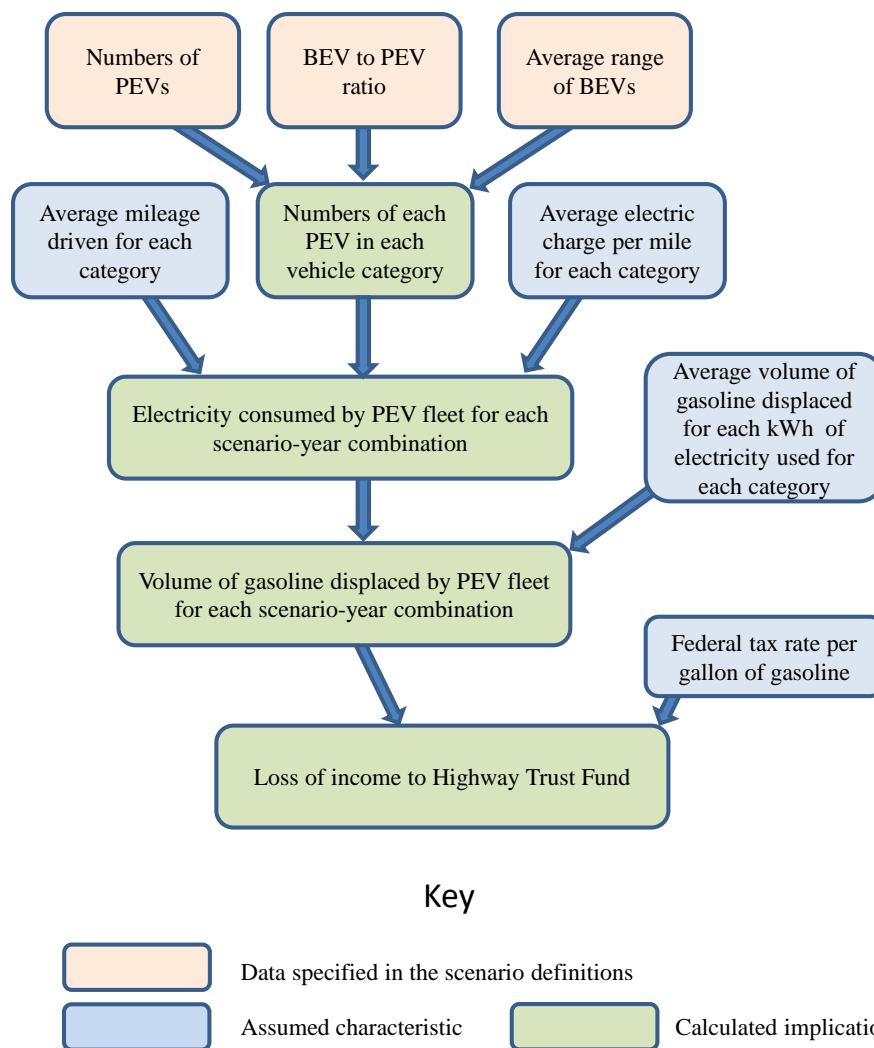


Figure 38: General methodology used to assess implications of PEV deployment

Three important inputs to the analysis are parameters that were defined during the scenario development process: (1) PEV numbers summarized in Figure 35; (2) BEV/PEV ratios shown in Figure 36; and (3) average BEV driving ranges shown in Figure 37 (these ranges come from AEO 2013 for Scenario 1, and are based on the foundational research for other scenarios).

To evaluate charging station infrastructure needs, the research team combined the electricity consumption calculated for the PEV fleet with the percentages of those vehicles charged at home and the work place, on or near the Interstate highway system, and at publicly accessible charging locations away from the Interstate system. The team combined these data and certain assumptions about the average charge transferred and connection times for different charging events to derive percentages, which can be used to estimate the number of charging events and the number of chargers required for both Interstate highway system charging and other publicly accessible charging.

The methodology used to analyze the implications for the different PEV deployment scenarios is shown schematically in Figure 39. The calculated number of chargers required and the amount of electricity they deliver are used in Section 3.6.2 to analyze the revenue impacts of these charging station implications.

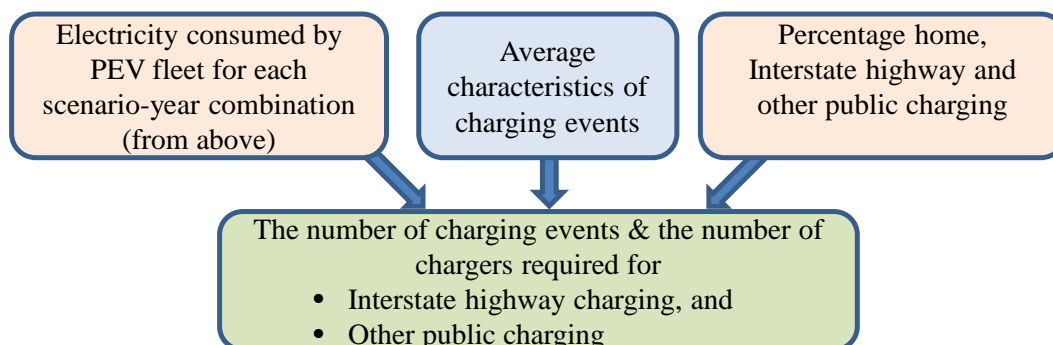


Figure 39: Methodology used to evaluate implications of PEV deployment scenarios on charging station infrastructure

Figure 52, which appears later in this report, follows shows the distribution of home/work, Interstate highway, and other publicly accessible charging across scenarios.

Qualitative analysis was conducted to better understand the profile of PEV owners for the various PEV deployment scenarios. The methodology is shown schematically in Figure 40.

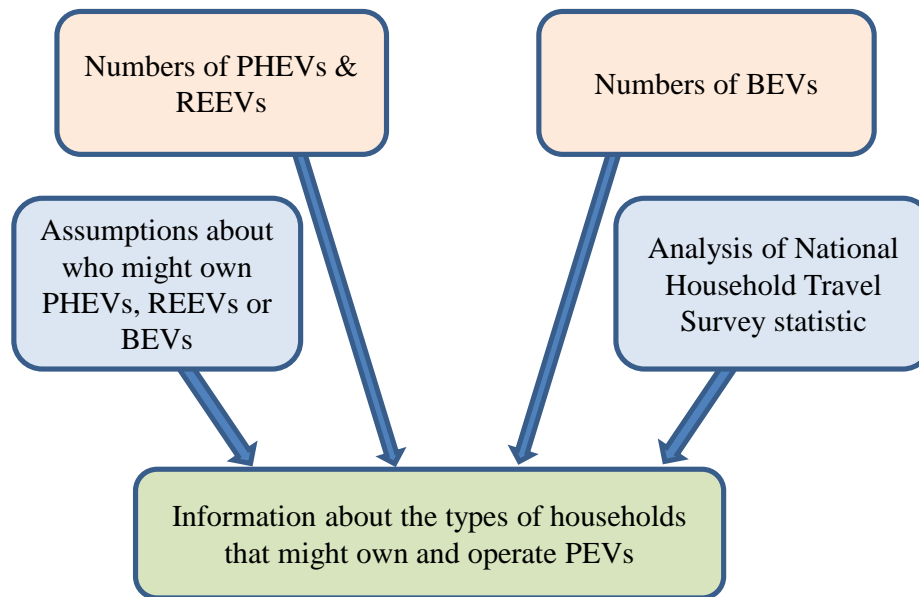


Figure 40: Methodology used to profile potential PEV owners

3.4 VEHICLE ANALYSIS RESULTS

3.4.1 PEV fleet composition, vehicle usage characteristics, electricity used, and fossil fuel displaced

For each scenario-year combination, the PEV fleet has four key characteristics:

- The numbers of the various types of PEVs.
- The annual miles traveled by the PEV fleet by vehicle type.
- The electricity used to travel these miles.
- The fossil fuel displaced due to vehicle-miles driven using electric energy.

The eight PEV deployment scenarios provide general descriptions of both the PEV fleet and the associated charging behavior. For this quantitative analysis, the PEV fleet is analyzed further, subdividing the PEVs into 10 distinct vehicle categories, as shown in Table 29. The vehicle category descriptions are generalized and are the same as those used in the AEO report.

Table 29: PEV vehicle categories used in the scenario analysis

Types of PEV - passenger cars	Types of PEV - light trucks
BEV 100-mile range	BEV 100-mile range
BEV 200-mile range	BEV 200-mile range
BEV 300-mile range	PHEV 10-mile range

Types of PEV - passenger cars	Types of PEV - light trucks
PHEV 10-mile range	PHEV 40-mile range
PHEV 40-mile range	-
PHEV 100-mile range	-

3.4.1.1 Numbers of each PEV vehicle category for the eight scenarios

The total number of all 10 PEV vehicle types corresponds to the total number of PEVs plotted in Figure 35. The total number of all five BEV vehicle types, divided by the total number of PEVs, corresponds to the BEV/PEV ratio defined in Figure 36.

The average of the numbers of BEV 100, 200, and 300, weighted by their range in miles, gives the average BEV range defined in Figure 37. Each weighted average value could correspond to any number of BEV range combinations. For example, an average range of 150 miles could be a product of: 50% BEV 100 and 50% BEV 200-mile range vehicles. Alternatively, it could be a product of: 75% BEV 100, 0% BEV 200, and 25% BEV 300-mile range vehicles. However, the latter possibility appears to be a substantially less likely combination, given the engineering and economic challenges associated with BEV 300 manufacture. For this reason, the analysis carefully evaluates the number of BEV vehicles in different range categories.

The scenarios define the numbers of PHEVs (derived from the number of PEVs minus the number of BEVs), but do not give any indication of the distribution across PHEV 10, 40, and 100. The analysis estimates this distribution based on information gathered during foundational research.

Values for years 2020–2040 in Scenario 1 are taken from the AEO 2013 projections, with the assumption that higher levels of PEV deployment will involve vehicles of similar or extended electric range.

The numbers of each PEV category given in Table 29 were detailed for the 2012 fleet, and for the target years of 2020, 2030, 2040, and 2050 for each of the eight scenarios, yielding 33 PEV fleet profiles.

Truck fraction of the light-duty vehicle fleet: Trucks currently represent a small percentage of the light PEV fleet. Recent sales figures indicate this trend is continuing, and the vast majority of current PEV light vehicle models—and those coming to the market in the near future—are passenger cars in a range of sizes, rather than light trucks. There is no generally recognized relationship between the number of passenger cars and light trucks, so the research team developed an equation to represent the relationship as part of this analysis. The number of PEV trucks relative to passenger cars is likely to rise in the future as PEV sales increase markedly. Therefore, a linear relationship does not seem appropriate, but a power series does, based on the professional judgment of the research team and information gathered during the foundational research. The equation used is:

$$\text{Truck fraction of vehicles} = 0.0001 \times (\text{Number of vehicles in fleet})^{1.5}$$

Figure 41: Equation for truck fraction of vehicles

In Figure 41, the number of vehicles is either the number of BEVs or (PHEV + REEV), not the total number of PEVs.

This relationship indicates that 0.32% of vehicle sales are trucks for a vehicle fleet size of 10 million, rising to 3.5% at 50 million, 10% at 100 million and reaching 18.4% at 150 million. This relationship is shown in Figure 42.

It should be noted that the relationship is proposed only for PEV fleet numbers up to 150 million vehicles, because this simple function will continue to increase, unchecked, beyond the point where the number of light trucks exceeds the number in the actual fleet. It is also noted that this predicts a lower deployment of trucks than the model reported in AEO 2013, which predicts that light truck sales will consistently represent about 8% of all PEV sales. PEV sales figures to date do not support this linear relationship.

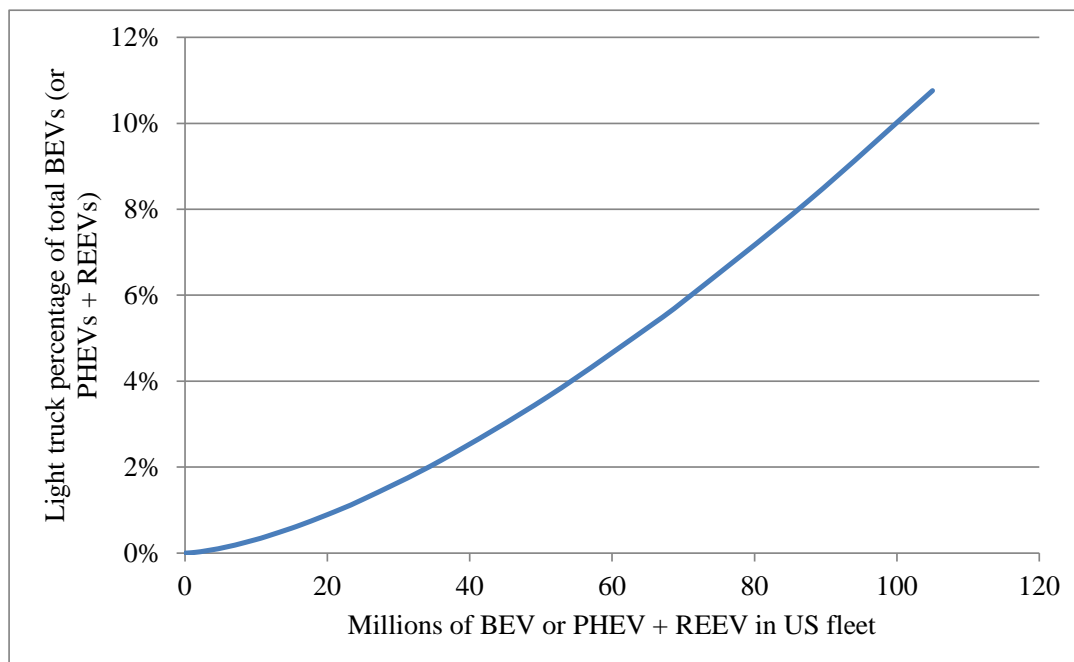


Figure 42: Light truck percentage of total BEVs (or PHEVs + REEVs) as a function of fleet size

From these data sources and relationships, the relative percentage of each of the 10 PEV categories can be calculated, as shown in Figure 43.

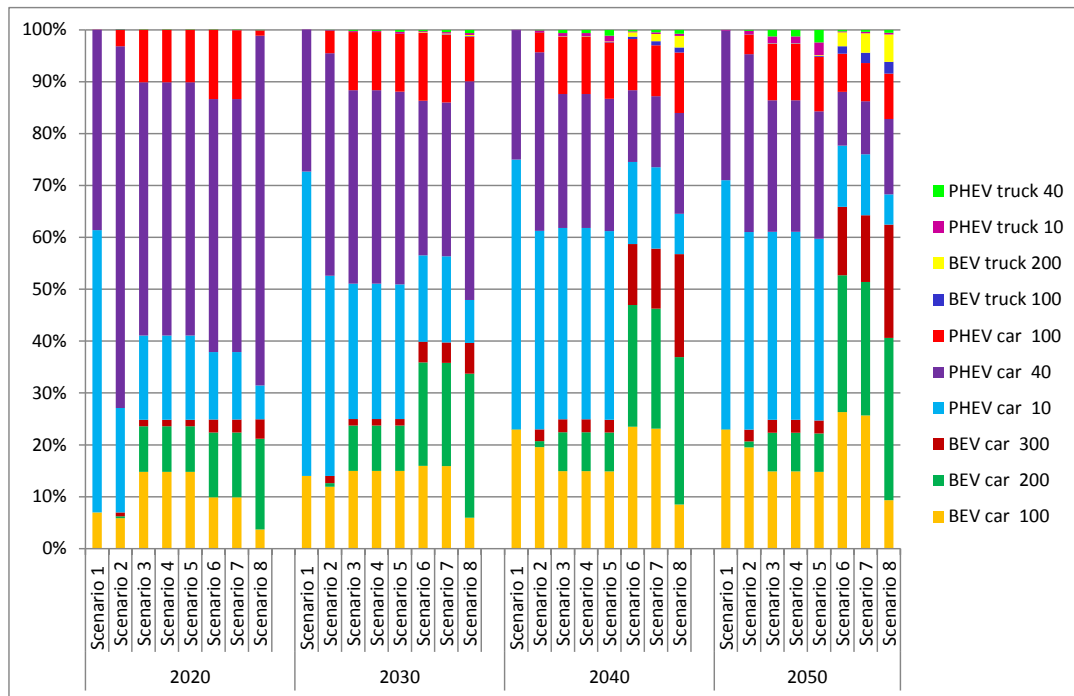


Figure 43: Composition of the PEV for each scenario-year combination

3.4.1.2 Average annual distance driven

This report presumes that the annual mileage traveled per vehicle in the PEV fleet is constant for each vehicle category and is independent of the scenario year. These values are given in Table 30.

Table 30: Average annual miles traveled per vehicle using electricity by PEV categories

Vehicle and range	Average electric mileage for passenger cars	Average electric mileage for light trucks
BEV 100-mile range	7,300	7,300
BEV 200-mile range	10,000	10,000
BEV 300-mile range	15,000	N/A
PHEV 10-mile range	2,500	2,500
PHEV 40-mile range	8,000	8,000
PHEV 100-mile range	12,000	N/A

The supporting evidence used to derive these figures is given in Appendix A: “Evidence used to define average annual mileage for the different PEV categories.”

The total miles traveled by the PEV fleet for each scenario-year combination is derived by multiplying the differing composition of the PEV fleet by the PEV fleet size as defined in each scenario, and then multiplying the product by the average miles traveled using grid electricity given in Table 30.

$$PEV \text{ fleet mileage} = PEV \text{ fleet size} \times \sum_C [(\% \text{ of fleet})_C \times (\text{Average mileage})_C]$$

Figure 44: Equation for PEV fleet mileage

Where:

- The PEV fleet size is defined for each scenario.
- C represents the 10 different PEV categories (shown in Table 30), and the summation is over all of these.
- $(\% \text{ of fleet})_C$ is the fleet composition for category C, as shown in Figure 43.
- $(\text{Average mileage})_C$ is the average mileage for vehicle category C, as shown in Table 30.

In this way, PEV fleet mileage can be calculated for each of the eight scenarios, for all four years.

3.4.1.3 PEV fleet electricity consumption by scenario

The estimated values for the average electric charge required to drive a mile (“PEV efficiency”) are given in Table 31. The supporting evidence used to derive these figures is given in Appendix B: “Evidence used to define average power consumption per mile driven for the different PEV categories.”

Table 31: Average power consumption per mile (kWh/mile) for different PEVs in 2012

Passenger cars	Average power consumption per mile for passenger cars	Average power consumption per mile for light trucks
BEV 100 mile range	0.30	0.80
BEV 200 mile range	0.33 ¹⁷	0.83 ¹⁸
BEV 300 mile range	0.363	N/A
PHEV 10 mile range	0.35	0.80
PHEV 40 mile range	0.368	0.83
PHEV 100 mile range	0.386	N/A

¹⁷ Assumes vehicles with the longer range are slightly heavier, requiring an additional 0.03 kWh/mile compared to the equivalent passenger cars

¹⁸ Assumes vehicles with the longer range are slightly heavier, requiring an additional 0.03 kWh/mile compared to the equivalent light trucks.

This report also assumes that PEV efficiency, shown in Table 31 for 2012, improves with time, at 0.3% per year between 2012 and 2020, at 0.8% per year between 2020 and 2030, and at 0.9% per year after 2030¹⁹. This trend leads to power consumption ranges for BEVs as given in Table 32²⁰. Similar ranges were developed for PHEVs using these same assumptions, and are also included in the table.

Table 32: Average power consumption per mile (kWh/mile) for different vehicle categories for specified years

Vehicle type and range	2012	2020	2030	2040	2050
BEV 100 mile passenger car	0.30	0.29	0.27	0.25	0.23
BEV 200 mile passenger car	0.33	0.32	0.30	0.27	0.25
BEV 300 mile passenger car	0.36	0.35	0.33	0.30	0.27
BEV 100 mile light truck	0.80	0.79	0.74	0.68	0.63
BEV 200 mile light truck	0.83	0.82	0.77	0.71	0.66
PHEV/REEV 10 mile passenger car	0.35	0.34	0.32	0.29	0.29
PHEV/REEV 40 mile passenger car	0.37	0.36	0.33	0.30	0.30
PHEV/REEV 100 mile passenger car	0.39	0.38	0.35	0.32	0.32
PHEV/REEV 10 mile light truck	0.80	0.79	0.74	0.68	0.63
PHEV/REEV 40 mile light truck	0.83	0.82	0.77	0.71	0.66

The PEV fleet size, as defined in the scenario, is multiplied by (1) the product of the differing composition of the PEV fleet, as shown in Figure 43, (2) the average miles traveled using grid electricity given in Table 30, and (3) the power required to travel each mile and summed over all 10 vehicle categories. This equation yields the fleet electricity consumption (FEC) per year for each scenario-year combination, as shown:

$$FEC = PEV \text{ fleet size} \times \sum_C [(\% \text{ of fleet})_C \times (\text{Average mileage})_C \times (\text{kWh per mile})_C]$$

Figure 45: Equation for fleet electricity consumption

¹⁹ This assumption regarding the average power consumption for BEV in future years does not have specific supporting evidence, but the research team views it as reasonable. Assuming no improvement in efficiency seems unduly pessimistic, but large changes in efficiency are constrained by fundamental principles of the physics of movement.

²⁰ Since the 1980s, improvements in ICE vehicle efficiency have generally been used to increase vehicle acceleration, weight, and peripheral amenities rather than increasing mpg. For example, average vehicle acceleration in the U.S. light-duty fleet improved by about 30% from the early 80s through the mid-2000s, while average mpg values held constant over this period (Bandivadekar, et. al. 2008). Given this tendency to “trade off” fuel consumption improvements for vehicle performance, the continuous improvements in kWh/mile assumed for PEVs in the future may be somewhat optimistic. However, such tradeoffs will be constrained to some extent by the implementation of more stringent CAFE standards.

Where:

- The PEV fleet size is defined for each scenario.
- C represents the 10 different PEV categories (shown in Table 30), and the summation is over all of these.
- $(\% \text{ of fleet})_C$ is the fleet composition for category C, as shown in Figure 43;
- $(\text{Average mileage})_C$ is the average mileage for vehicle category C, as shown in Table 30.

$(\text{kWh per mile})_C$ is the average quantity of electricity required to travel each mile for vehicle category C, as shown in Table 31 and Table 32.

These fleet electricity consumptions are shown in Figure 46. Because of the large dynamic range involved, electricity consumption is plotted using a logarithmic scale.

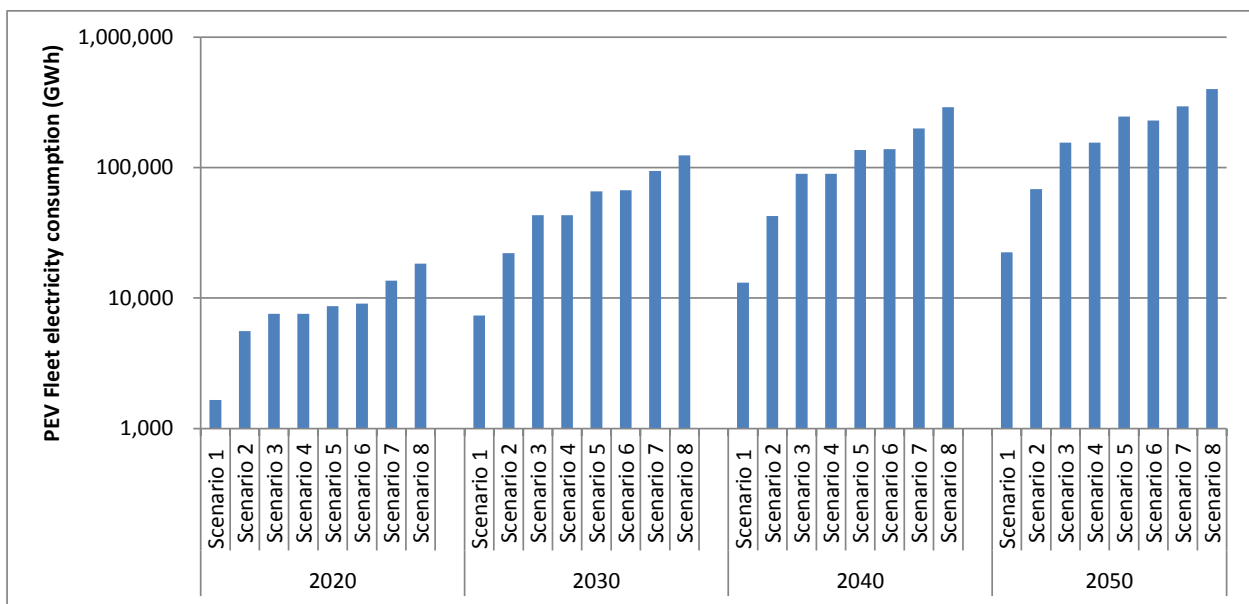


Figure 46: Annual PEV fleet electricity consumption by scenario

Values range from approximately 1,650 GWh for Scenario 1 in 2020, to approximately 400,000 GWh for Scenario 8 in 2050.

These values are compared against the projected U.S. electricity consumption (AEO Reference Case electricity delivered to consumers) in Table 33. The table shows that by 2040 (the latest year included in AEO 2013 projections) PEV fleet electricity consumption is predicted to fall between 0.29% and 6.3% of the total delivered electricity consumption.

Table 33: Comparison of PEV fleet electricity consumption and AEO2013 projections to 2040

Fleet electricity consumption	2020	2030	2040
Delivered electricity consumption, all sectors (GWh) (EIA, 2013b)	3,968,242	4,275,155	4,606,721
Annual PEV fleet electricity consumption for Scenario 8 (GWh)	18,365	124,021	290,265
Annual PEV fleet electricity consumption for Scenario 8 expressed as % of “Delivered electricity consumption”	0.46%	2.90%	6.30%
Annual PEV fleet electricity consumption for Scenario 1 (GWh)	1,653	7,336	13,139
Annual PEV fleet electricity consumption for Scenario 1 expressed as % of “Delivered electricity consumption”	0.04%	0.17%	0.29%

Checking the preceding assumptions against AEO 2020 projections: Scenario 1 uses AEO 2013 vehicle numbers for BEV 100- and 200-mile range, PHEV 10- and 40-mile ranges for passenger cars and trucks. In addition to the fleet numbers for 2020, the AEO 2013 also gives the electricity consumed by these vehicles, calculated using an EIA model²¹.

To calculate total electricity consumption for the different types of PEVs, we can use the same PEV fleet composition as was used in AEO 2013, multiplied by our assumed average miles traveled for each PEV type, and multiplied again by our assumed electricity consumption per mile for each PEV type.

For 2020, AEO 2013 predicts 1,776 GWh of total electricity consumed annually by the PEV fleet. Our calculation predicts 1,652 GWh. These two figures are within 7.5% of each other.

For 2030 and 2040, AEO 2013 predicts 5,300 and 10,900 GWh of PEV electricity consumption, respectively. Using the same fleet composition, our quantitative assessment predicts 7,330 and 13,100 GWh, respectively. These figures are, respectively, 28% and 17% lower than AEO 2013.

These independent points of reference help confirm the reasonableness of the assumptions used within this quantitative assessment.

3.4.1.4 Average volume of gasoline displaced per EV-mile

The type of fossil fuel displaced by PEVs is assumed to be predominantly gasoline. AEO 2013 gives the percentage of the energy supplied to light vehicles by diesel fuel as 0.25% in 2010, rising to 2.1% by 2020, and to 3.3% by 2040. However, the diesel-fueled light vehicles of the future are likely to be larger, more energy-intensive small trucks that are not as easily replaced by PEVs, compared to the vast majority of passenger cars and light trucks. Therefore, in this analysis, we ignore any displacement of diesel fuel, and assume all the fuel displaced is gasoline.

²¹ This is given in trillions of Btu. It can be converted to GWh using the conversion factor 1 trillion Btu = 293.07 GWh.

Calculating the amount of gasoline displaced by the deployment of PEVs, where the energy used to provide mobility changes from gasoline to electricity, requires some measure of equivalence. According to U.S. DOE, one gallon of gasoline produces energy equivalent to that produced by 36.42 kWh of electricity²². However, this is purely energy equivalence, such as comparing the amount of gasoline and electricity required to heat a fixed amount of water. Our assessment requires a “mobility” equivalence, rather than a simple energy equivalence, which takes into account the relative efficiency of the gasoline-fueled internal combustion engine and the electric motor, and their drive trains. This equivalence is obtained from measuring how much gasoline or electricity is required to travel a mile on average.

It is difficult to compare BEVs with equivalent gasoline models, because very little fuel consumption data exists for pairs of electric and equivalent conventional powertrain vehicles. For BEVs like the Nissan LEAF, which have reliable kWh/mile data, the lack of a gasoline equivalent makes it difficult to undertake the comparison.

The approach used in this research is to consider PEVs where the same vehicle can be driven using electric or gasoline power. Based on this approach, we assume that 13 kWh electricity is equivalent to one gallon of gasoline for all PEVs—i.e. for PHEVs, REEVs, and BEVs—for passenger cars and trucks in 2012.

The supporting evidence used to derive these figures is given in Appendix C: “Evidence used to define the average number of kWh required to displace a gallon of gasoline.” Some uncertainty exists regarding the 13 kWh/gallon figure. Plausible averages vary across a range from 9–17 kWh/gallon. This range is informed by the performance of the Chrysler RAM ARRA project (~10 kWh/gallon) and the gasoline-efficient Ford Fusion Energi and Ford C-Max Energi (~15 kWh/gallon), with a small margin included at both the high and low ends of the range.

The average volume of gasoline displaced per EV mile driven is anticipated to vary over time from the 13 kWh/gallon value used for 2012, as the efficiency of both PEVs and ICEs change over time. ICE efficiency will improve due to the influence of the latest CAFE standards. If the efficiency of PEVs increase relative to ICEs, then fewer kWh are required to replace each gallon of gasoline, and the equivalence will become smaller than 13 kWh/gallon. Conversely, if the efficiency of ICEs increase relative to PEVs, then more kWh are required to replace each gallon of gasoline, and the equivalence will become larger than 13 kWh/gallon. This relationship is discussed in detail in Appendix C: “Evidence used to define the average number of kWh required to displace a gallon of gasoline.”

These figures are for temperate climates. It is well documented that PEVs consume more electricity when travelling in hot, cold, or hilly environments. This performance difference is not explicitly considered in this analysis. However, the following section of this analysis does consider the quantity of gasoline displaced by the PEV as a range of equivalences, and these

²² This equivalence is given in <http://www.netl.doe.gov/energy-analyses/energy-calc.html>

PEV performance differences, when averaged over a year of driving, will fall within the range given.

The time-dependent efficiencies of PEVs (taken from our analysis), and ICEs (calculated from AEO 2013) are described in Appendix C: “Evidence used to define the average number of kWh required to displace a gallon of gasoline,” and are shown in Figure 47 below. The thick green line (top) shows their combined effect.

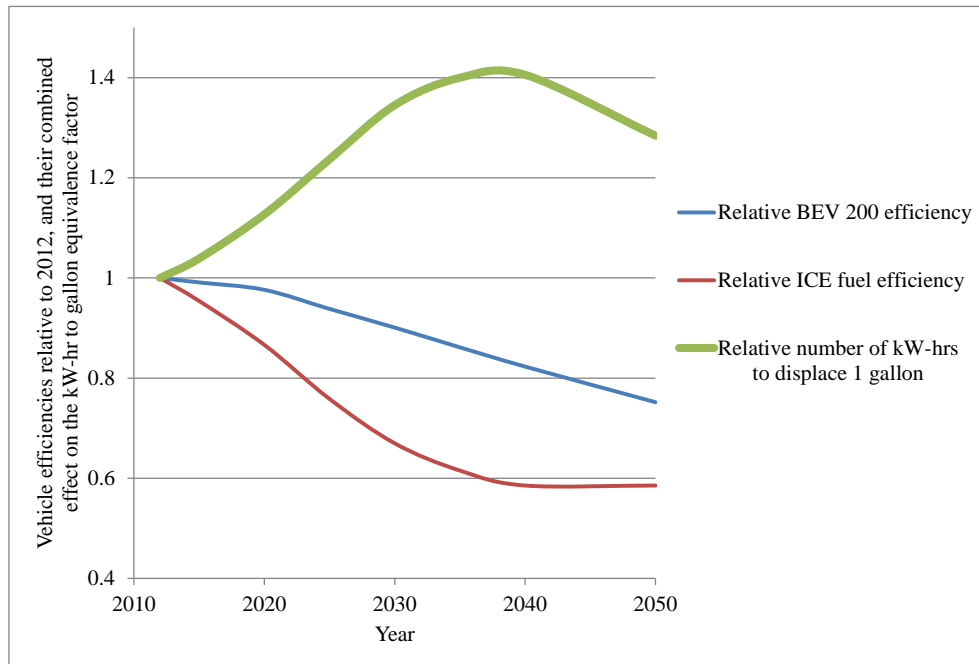


Figure 47: The projected relative efficiencies of PEVs and ICEs, and their combined effect on the kWh to gallon consumption ratio

The overall ratio of electricity to gasoline consumption used in this analysis are shown in Table 34, below.

Table 34: Ratio of electricity to gasoline consumption

Year	2012	2020	2030	2040	2050
Energy equivalence kWh per gallon of gasoline	13.0	14.6	17.5	18.3	16.7

This is far from a smooth function. It increases until just before 2040, because of the projected phased improvement in energy efficiency of ICE vehicles, dominating the more modest improvement in energy efficiency of PEVs. After 2040, it diminishes due to the leveling-off of projected ICE vehicle energy efficiency improvements, but continued modest improvement in energy efficiency of PEVs.

3.4.1.5 Quantities of gasoline displaced by the PEV fleet

When the annual PEV fleet electricity consumption associated with each of the scenarios (Figure 46) is divided by 13 kWh, the resulting numbers represent the gallons of gasoline displaced, which are shown in Figure 48. This is effectively a scaled version of Figure 46.

However, the analysis in Appendix C: “Evidence used to define the average number of kWh required to displace a gallon of gasoline” indicates some uncertainty regarding the number of kWh equivalent to a gallon of gasoline. As discussed above, the plausible range is 9–17 kWh/gallon of gasoline. For the ends of the plausible range, the quantities of gasoline displaced by the PEV fleet would simply be a scaled version of Figure 48. For 9 kWh/gallon equivalence, the volume of gasoline displaced would be 44% greater than Figure 48 (i.e., scale the values in Figure 48 by multiplying by 1.44). For a 17 kWh/gallon equivalence, the volume of gasoline displaced would be 23.5% less than Figure 48 (i.e., scale the values in Figure 48 by multiplying by 0.765).

For PHEVs and REEVs, the analysis assumed that their gasoline consumption is included in the AEO 2013 baseline scenario. For these vehicles, the quantity of gasoline displaced is estimated based on their annual mileage supported by charging (see Table 30) and their average power consumption per mile (see Table 31 and Table 32). Dividing the resulting PHEV and REEV annual power consumption by the energy equivalence ratios given in Table 34 yields the quantity of gasoline displaced.

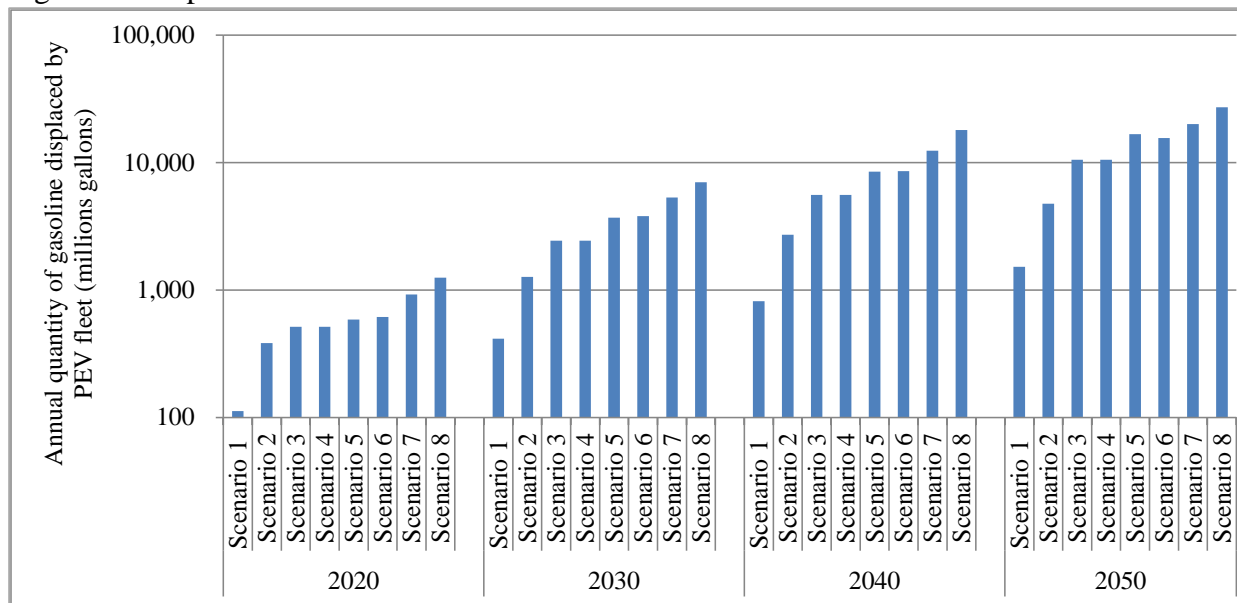


Figure 48: Decrease in annual volume of gasoline consumed by the U.S. light vehicle fleet due to PEVs, for each scenario

In addition to some uncertainty in the number of kWh required to displace a gallon of gasoline, uncertainty also exists regarding future VMT for the various PEV deployment scenarios. Several

research studies suggest that the trends in both auto ownership and VMT are flattening out or even declining. If these effects continue, the results of our analyses still generally stand, because the trends would affect both the baseline and the various PEV scenarios equally (within the assumptions clearly stated regarding the annual mileage of PEV vehicles).

Also worth considering is the linkage between the distance driven by PEVs, the cost of driving them, and BEV range limitations. These interesting potential variables mean that ICE-to-PEV mileage exchanges are not purely one-to-one and would affect VMT, and consequently, the volume of gasoline displaced. However, they are outside the scope of the present study, which assumes a mile-for-mile displacement.

The financial impacts of these assumptions are assessed in Section 3.6.2. The reasonableness of the data in Figure 48 was assessed by comparing the data with the total amount of gasoline consumed by light duty vehicles as predicted by AEO 2013. This comparison is shown in Table 34. The AEO 2013 values are given in the top row of Table 35, with predictions for Scenarios 1 and 8 (the lower and upper bounds of the volumes of gasoline displaced) given in subsequent rows. As seen in the top row of the table, AEO projections assume a substantial decrease in total gasoline consumption over time, due to increased efficiency of the ICE vehicle fleet. Therefore, all future gasoline displacement resulting from PEV adoption occurs against this baseline of decreasing vehicle energy consumption.

The fraction of the AEO-predicted gasoline consumption that would be displaced, and the fraction of the light vehicle fleet that would be PEVs, are shown in the last two rows of the table. These data seem reasonable, with the percentage of the gasoline displaced being somewhat less than the percentage of the light duty fleet represented by PEVs. This is expected, because some of the PEVs are PHEVs and REEVs, which will use some gasoline, and the average distance traveled by PEVs is assumed to be somewhat below the average for ICE vehicles. The percentage of gasoline consumption predicted to be displaced as a ratio of the percentage of the PEVs in the light vehicle fleet changes from approximately a factor of three in 2020 to less than a factor of two in 2050. This change arises due to the trend towards PEVs having a greater range in the future. On this basis, the predictions regarding replacement of gasoline consumption by electricity are reasonable.

Table 35: AEO 2013 annual gasoline consumption predictions compared to the volume of gasoline displaced by PEV deployment Scenarios 1 and 8

Year	2020	2030	2040	2050
AEO 2013 predictions for gasoline used in U.S. (millions gallons)	125,655	111,772	108,777	108,777 ²³
Scenario 1 predictions (lower bound) for gasoline displaced by U.S. PEV fleet (millions gallons)	112	414	816	1,524
Scenario 8 predictions (upper bound) for gasoline displaced by U.S. PEV fleet (millions gallons)	1,249	7,007	18,029	27,189
% of U.S. gasoline consumption displaced (see Note 1)	0.09–0.99%	0.37–6.27%	0.75–16.57%	1.40–25.00%
PEVs as % light vehicle fleet (see Note 1)	0.38–3.34%	1.31–19.05%	2.23–38.78%	3.31–49.67%

Note: Data are given as a range corresponding to the percentages for Scenarios 1–8.

3.4.2 PEV purchasers

The potential buyers, types, and ways of using PEVs are fundamentally different for BEVs and for non-BEV PEVs. Vehicles in the latter group have an internal combustion engine (ICE) and do not need to be charged away from home at all, because they can use their gasoline engine should the battery charge run out. BEV drivers, on the other hand, need to consider their usage patterns more carefully, to take account of the BEV's limited range and the limited charging opportunities.

3.4.2.1 PHEVs and REEVs

Purchasers of PHEVs and REEVs are likely to view the vehicle as a potential direct replacement for a current ICE vehicle. The decision regarding the attractiveness of purchasing a PEV is likely to involve two key factors:

- Economic factors (e.g., cost of buying, operating, and maintaining the vehicle).
- Emotive factors such as:
 - Being an early adopter and innovator.
 - Reducing one's personal carbon footprint.
 - Reducing dependence on foreign oil.
 - Making an environmental statement.

²³ The volume listed for 2050 is the same volume listed for 2040, because EIA's AEO 2013 energy outlook only goes through 2040.

In the future, it appears likely that PHEV/REEV technology will become proven, widely available, and of clear economic benefit. Extended-range vehicles will very likely become closer in price to conventional ICE vehicles, and as that happens, their electric driving ranges will increase, enabling the PHEV/REEV market to extend relatively rapidly beyond early adopters. However, certain potential users may still be deterred from owning PHEVs and REEV—for example, those whose residential situation makes at-home charging difficult due to multi-family dwellings or lack of off-street parking. Overall, PHEV/REEV adoption is anticipated to have relatively little impact on the need to provide charging stations.

3.4.2.2 BEVs

Determining who is likely to buy a BEV, and how they use it, depends on the timeframe, the maturity of the market, and the supporting infrastructure available. The current state of PEV technology, specifically the current range of batteries, fits best with the needs of urban residents in terms of average daily commute distances and available infrastructure. The typical average commute distance in the United States is a round-trip of 25 miles per day (US Department of Transport, 2009). Both private and public entities are developing charging infrastructure in urban environments (The EV Project, 2012).

Rural charging stations are being planned in certain regions, specifically in Oregon where the Oregon Department of Transportation received a \$2 million federal stimulus grant (a U.S. DOT TIGER grant) to finance installation of DC Fast chargers. However, in most states there is no comprehensive charging infrastructure systematically linking rural areas to urban areas.

Two publicly available surveys that classify the demographics of near-term EV customers were reviewed in this project's Foundational Research Summary: the California Center of Sustainable Energy's *California Plug-In Electric Vehicle Owner Survey* (Center for Sustainable Energy California, 2012); and Zpryme's *The Electric Vehicle Study* (Zpryme, 2010). These studies reach similar conclusions about early adopters:

- The majority are male.
- Most live in two-person households.
- Most also own a conventional, gasoline-powered vehicle.
- Most own a single-family home.

Building on these conclusions—i.e., by considering only two-person households that already own a second car—it is possible to determine which scenario years could be accommodated for both the projected PEV and BEV numbers. The 2009 National Household Travel Survey or NHTS (FHWA, 2009) indicates that there are approximately 37.7 million two-person households in the United States; that about 71.5% of people have a car; and that there are, on average, 1.86 cars per household. If it is assumed that 70% of the 37.7 million two-person households have two cars, this would indicate a potential market for 26 million vehicles.

Figure 49 shows a matrix of the eight scenarios and the four years, 2020, 2030, 2040, and 2050. For each scenario-year combination, the number of PEVs in the fleet (left-hand matrix), or BEVs

in the fleet (right-hand matrix), is categorized relative to the 26 million two-person, two-car households.

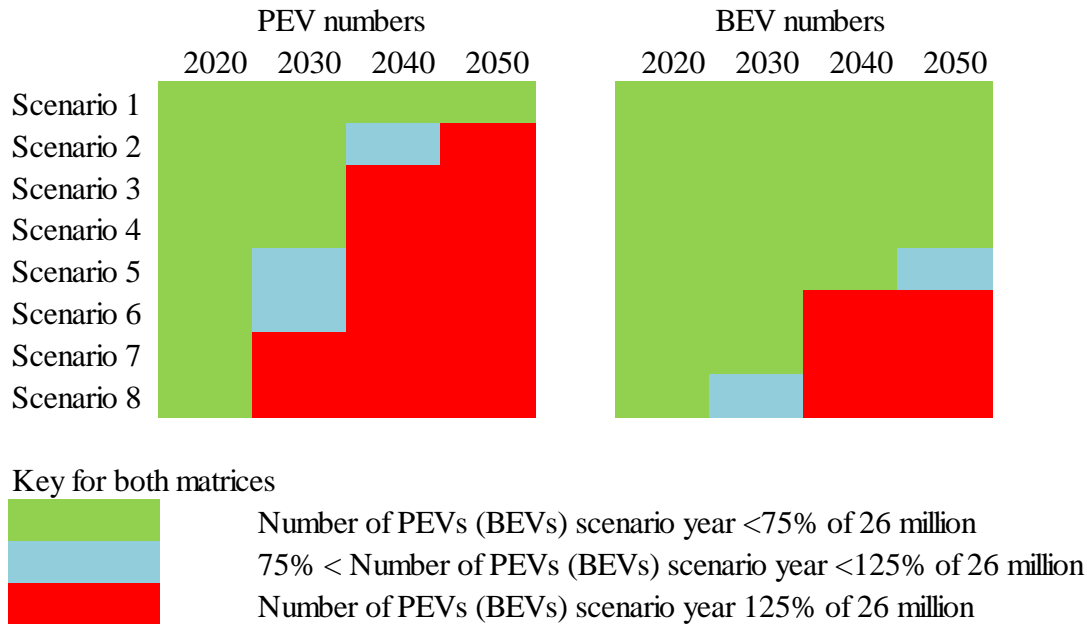


Figure 49: Matrix of which scenario-year combinations have PEV, or BEV, fleet deployment numbers within the number of two-person, two-or-more-car households

The figures show that if PEV ownership is restricted to this group of near-term customers, the PEV fleet figures for 2020, and BEV figures for 2030 could be met for all scenarios. To meet the PEV deployment numbers for Scenarios 7 and 8 in 2030, and Scenarios 3–8 in 2040, groups other than those in two-person households that owned a second car would need to purchase PEVs.

It is possible to alter the purchasing criterion such that all second, third, and fourth (and so on) cars in a household could potentially be PEVs. Analysis of the data in Table 5 of the 2009 NHTS indicates that 59% of households have more than one car, and that 51% of cars are second (or third, etc.) vehicles (see Figure 50 and Figure 51). This is in the context of the NHTS indicating that there are 210 million “household” cars in 2009. If this proportion remains unaltered out to 2050, then in 2050, 154 million of the 302 million vehicles would be second vehicles (or third, etc.). Under these circumstances, all of the PEVs forecasted for all eight scenarios out to 2050 could be second vehicles. This includes the 105 million BEVs forecasted for Scenario 8 in 2050.

Such PEV purchasing patterns would mean that the demand for charging infrastructure would be influenced by the fact that a large fraction of households would retain access to gasoline vehicles for long trips in all scenarios envisioned. This is distinctly different from the situation for households only owning BEVs, which would either be dependent on appropriate infrastructure being in place, or would have to make other arrangements for trips outside of the BEV’s range.

It should be noted that there is considerable uncertainty as predictions are made further into the future. For example, while the AEO predicts increased vehicle miles traveled (VMT) into the future, this is not guaranteed. Vehicle purchasing patterns may be changing, and there is considerable discussion in transportation planning circles about declining vehicle ownership trends and declining VMT. This is especially true for younger people (TIME Magazine, 2013).

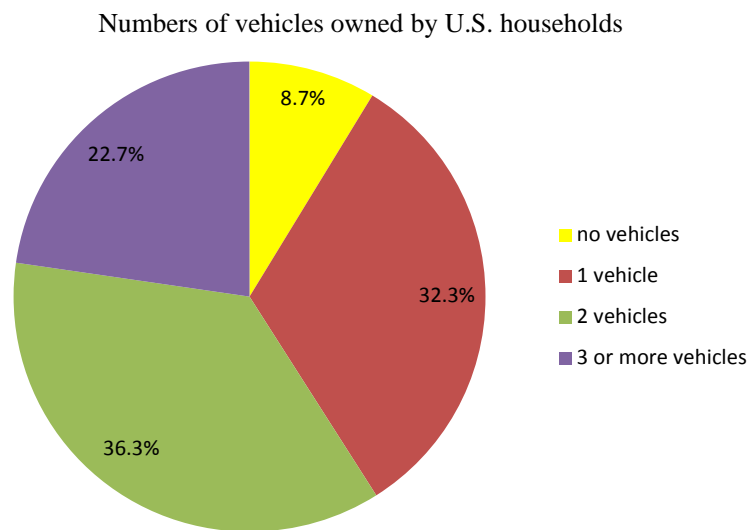


Figure 50: Fraction of U.S. households owning 0, 1, 2, and more than 2 vehicles

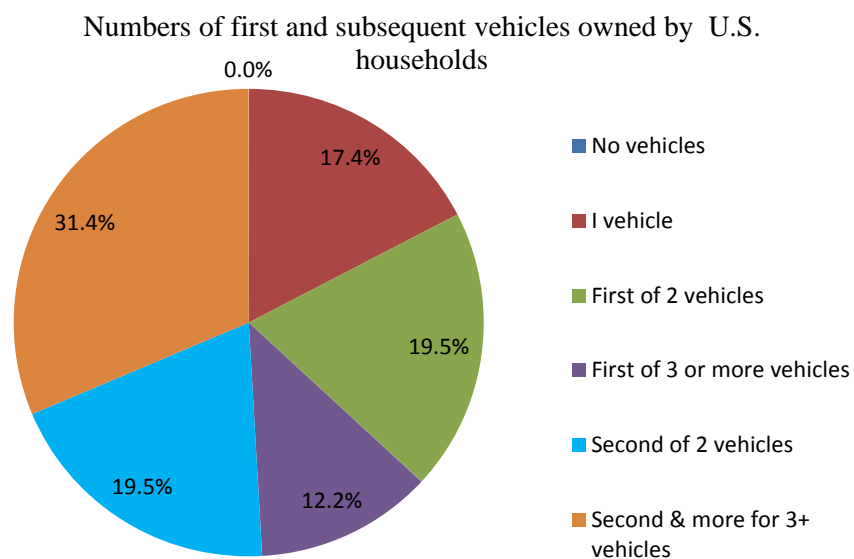


Figure 51: Breakdown of vehicles into first, second, third, etc. vehicles in a household

3.5 EVSE ANALYSIS RESULTS

3.5.1 Charging locations

The quantity of electricity used by PEVs for the various scenario-year combinations is calculated in Section 3.4.1.3. During the development of the scenarios, charging was presumed to occur at one of the following locations:

- At home or at work.
- At local destinations, using publicly accessible chargers.
- Mid-trip, using publicly accessible chargers on or near the Interstate right of way (ROW).

This categorization does not differentiate between minor roads and roads within the National Highway System. It does, however, differentiate the approximately 47,000 miles of the Interstate system.

The charging behavior specified in the scenario definition is summarized in Figure 52.

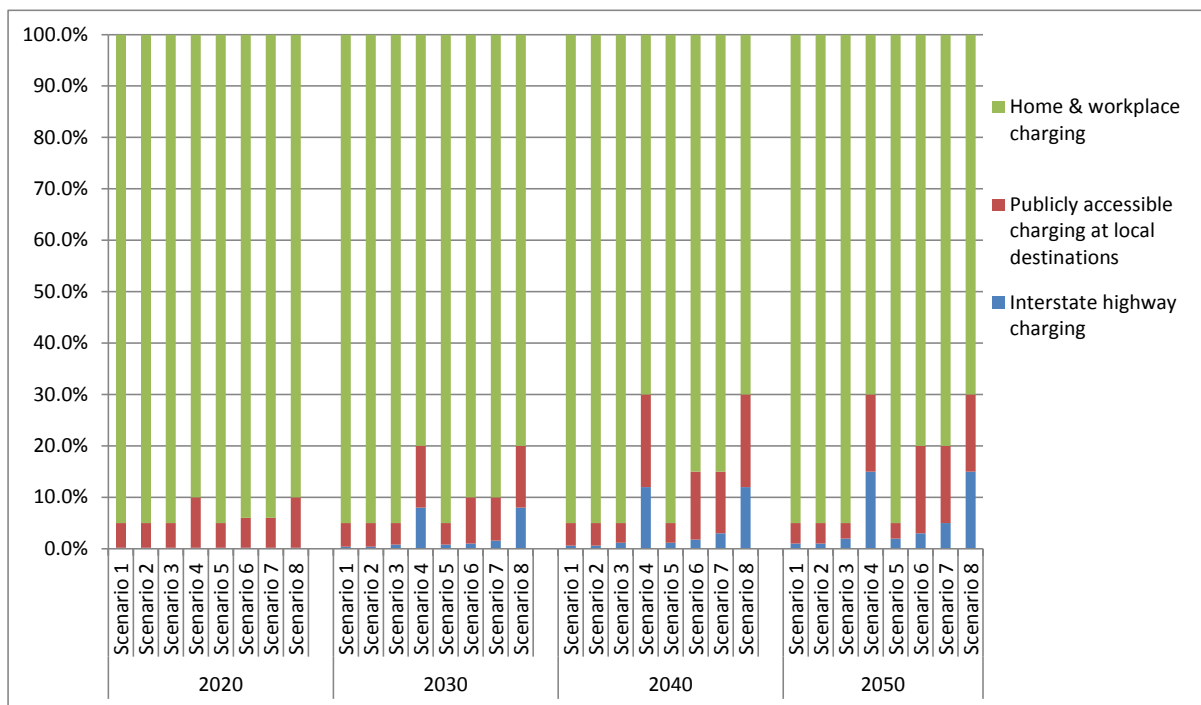


Figure 52: Charging location percentage by scenario and year

By 2020, it is assumed that 95% of charging occurs either at home or at the workplace for the majority of scenarios. The exception is tested in Scenarios 4 and 8, where it is assumed that an increased amount of charging (10%) is away from the workplace and home. For all eight

scenarios in 2020, it is assumed that only 0.2% of charging events occur on or near Interstate highways.

By 2030, the scenarios span a much greater variation of charging options. In Scenarios 1, 2, 3 and 5, it is assumed that 95% of charging occurs either at home or at the workplace. Charging away from home or the office rises to 10% in Scenarios 6 and 7, and to 20% in Scenarios 4 and 8. The amount of Interstate highway charging similarly varies from 0.4% in Scenarios 1 and 2, to 0.8% in Scenarios 3 and 5, to a maximum of 8% in Scenarios 4 and 8, which investigate the implications of substantial Interstate highway charging occurring for different PEV and BEV deployments (4.75 million BEVs out of 19 million PEVs for Scenario 4, and 20 million BEVs out of 50 million PEVs for Scenario 8).

The blue portion of Figure 52 represents the percent of PEV charging that occurs on or near the Interstate highway. It is a very small proportion of the whole, except for in Scenarios 4 and 8, due partly to the assumption that the installation of commercial charging station in Interstate rest areas is unlikely in the near term. One statutory prohibition against this possibility is Title 23 of the U.S. Code (Highways) Sub-section 111, which is a long-standing policy that is unlikely to change in the near term given the current political climate in the United States. In addition, language in MAP-21 appears to prohibit the installation of electric charging stations in general (regardless of the funding source) from being located on the rights-of-way of the Interstate System. FHWA will need to fully explore the exact implications of this seemingly conflicting direction in MAP-21, as the question requires legal and policy analysis outside the scope of this project.

The divergence of charging options is most evident in 2050. Scenario 1 presumes only very modest PEV uptakes, with 10 million PEVs in the fleet (of which approximately 2.4 million are BEVs), 95% of charging occurring at home and the workplace, and only 1% using Interstate highway charging points. On the other hand, Scenario 8 presumes enormous growth in electric vehicles, with 150 million PEVs in the fleet, of which 105 million are BEVs. Even with these numbers, it is presumed the majority of charging occurs at home and the workplace (70%) because that is consistent with anticipated vehicle usage patterns and the anticipated extended range of vehicles (only 15% being BEV 100-mile range, 50% being BEV 200-mile range, and 35% of BEVs having a 300-mile range). This scenario also predicts that 15% of away-from-home charging will occur using charging stations on or near the Interstate highway.

The reasonableness of these charging scenarios can be checked against VMT statistics. FHWA annual vehicle miles of travel (VMT) estimates for 2013 indicate that 24.6% of the approximately 3,000 billion miles traveled were on the Interstate (8.3% in rural areas and 16.3% in urban areas). Therefore, the assumption in Scenario 8 that 7.5% of all charging (50% of charging away from home or work) occurs on or near the Interstate is roughly consistent with EV usage patterns approaching those for gasoline vehicles where 8.3% of all VMT occurs on Interstate travel in rural areas. This reflects that the likelihood of needing to charge a PEV on longer Interstate journeys is higher than for shorter journeys on local roads. The lower percentages of in-journey charging for other scenarios reflects the assumption that EV usage patterns differ from that of gasoline cars, with some BEV owners choosing to use a second

(gasoline) car or rental car for long highway trips, thereby reducing the demand for in-journey charging. Further discussion regarding the potential demand for Interstate charging is presented in Section 2.4.

Using these scenario definitions, and the vehicle data discussed in the previous section, the amount of charge (kWh) added to all PEVs (categorized by the different PEV types) has been calculated and can be apportioned to home and work charging, publicly accessible charging at local destinations, and Interstate highway charging. This approach quantifies the need for publicly accessible charging. Given some assumptions about the amount of charge transferred, and the charging rate, it is possible to derive annual estimates for key parameters relevant to publicly accessible charging stations.

3.5.2 Characteristics of charging events using publicly accessible charging stations

Key parameters for the assessment of charging at publicly accessible charging stations include:

- The average amount of charge transferred per charging event.
- The average amount of time the PEV spends linked to the publicly accessible charging station.

This assessment assumes that charging on or near the Interstate system will necessarily be DC Fast charging. The rationale for this assumption is that Interstate travel is used when travel from the start point to end point is desired in a minimum amount of time.

The assessment also assumes that charging at local destinations uses Level 2 AC charging. This is a “worst case” and “safest case” baseline. “Worst case” refers to a higher number of charging stations required due to a slower charging rate, relative to DC Fast charging, making overall connection times longer. “Safest case” reflects that all PEVs are designed to use Level 2 AC charging, whereas not all are equipped for DC Fast charging, and because commercially, the cost of providing Level 2 charging stations is much lower than for DC Fast charging stations. However, it is likely that some charging points at local destinations will actually be DC Fast charging stations.

Given the charge transferred per charging event and the amount of charge transferred to all PEVs using publicly accessible charging stations (as derived from the scenario definition), it is possible to calculate the number of annual vehicle visits to each type of publicly accessible charging station.

The values assumed in this analysis are given in Table 36. The supporting evidence used to derive these figures is given in Appendix D: “Evidence used to support the assumptions made about charging characteristics at publicly accessible charging points.”

Table 36: Assumptions regarding the characteristics of charging events at publicly accessible charging stations

	Publicly accessible charging not on or near the Interstate highway system	Publicly accessible charging on or near the Interstate highway system	Publicly accessible charging on or near the Interstate highway system
Type of charging station	Level 2	DC Fast charging	Tesla Super charging system
Average charge transferred per charging event	10 kWh (33 mile range)	20 kWh (66-mile range)	60 kWh (200-mile range (Teslamotors.com, 2013a))
Rate and duration of charge transfer	7.5 kW; 80 minutes	50 kW; 24 minutes	120 kW; 30 minutes
Average length of time vehicle is connected to the charging point	5 hours, reducing to 2.5 hours as etiquette becomes established (see Note 1)	30–40 minutes (see Note 2)	40 minutes
Average number of charging events per year per charging point	75	1,000	1,000

Notes:

1. Because charging electric vehicles is a new technology, social protocols, or “charging etiquette,” are not really established. This can make it “acceptable” to leave a vehicle occupying a charging place for far longer than is required to obtain the required, because of the low-current demand and lack of a reason to move the vehicle. This may change in the future as demand increases.
2. The difference between 24-minute charging duration and 30–40-minute connection time can be viewed as a longest average case scenario, where the vehicle driver (and passengers) take a break while the vehicle is charging. In the case of DC Fast charging, actual behavior may mirror typical retail gasoline station behavior, where the motorist is more likely to be in a hurry and watching the charge level closely. Hence this time may be considerably closer to 24 minutes.

It might be considered unrealistic to assume that these charging protocols, rates, and durations will remain constant over the next four decades. If technological changes occur that lead to faster charging rates and lower durations for connections, then the assumptions given in Table 36 represent a worst case situation, and the number of charging points required would be less than the number calculated in the following analysis.

3.5.3 Number of charging events using publicly accessible charging stations

Certain regions of the United States, including California and the Northeastern region, exhibit a sizeable PEV market share in 2013 (Figure 54 and Figure 55), and that prevalence is expected to grow significantly between now and 2050.

From the assumptions given in Table 36, the following are calculated:

- Number of charging events²⁴ per year at non-Interstate highway system publicly accessible charging points (i.e. at local destinations).
- Number of charging events per year at Interstate highway system publicly accessible charging points.

The number of charging events for the different charging point types is calculated using the following equation:

$$(No. \text{ of charging events})_{CPT} = (Total \text{ Charge})_{CPT} \times (\% \text{ charge supplied})_{CPT} / (\text{charge per visit})_{CPT}$$

Figure 53: Equation for the number of charging events for each charging point type

Where:

- CPT is an abbreviation for each Charge Point Type.
- $(Total \text{ Charge})_{CPT}$ = Total amount of charge supplied for each charge point type.
- $(\% \text{ charge supplied})_{CPT}$ = Percentage of this charge supplied through each charging point type (Figure 52).
- $(\text{charge per visit})_{CPT}$ = Charge added per visit (Table 36).

The number of charging events is calculated for each scenario-year combination. Results are shown in Figure 56 and Figure 57. Because of the large dynamic range involved, these events are plotted using a logarithmic scale.

The number of hours that vehicles are attached to charging points is simply the product of the number of charging events and the average connection duration. The average number of hours is used in the section below to determine the average number of charging events that could occur for publicly accessible charging station. From this, one can estimate the number of Level 2 and DC Fast charging points required to provide the above number of charging events.

²⁴ The Idaho National Laboratory reports refer to the numbers of connections. The terminology used in this report is to refer to each connection as a charging event.

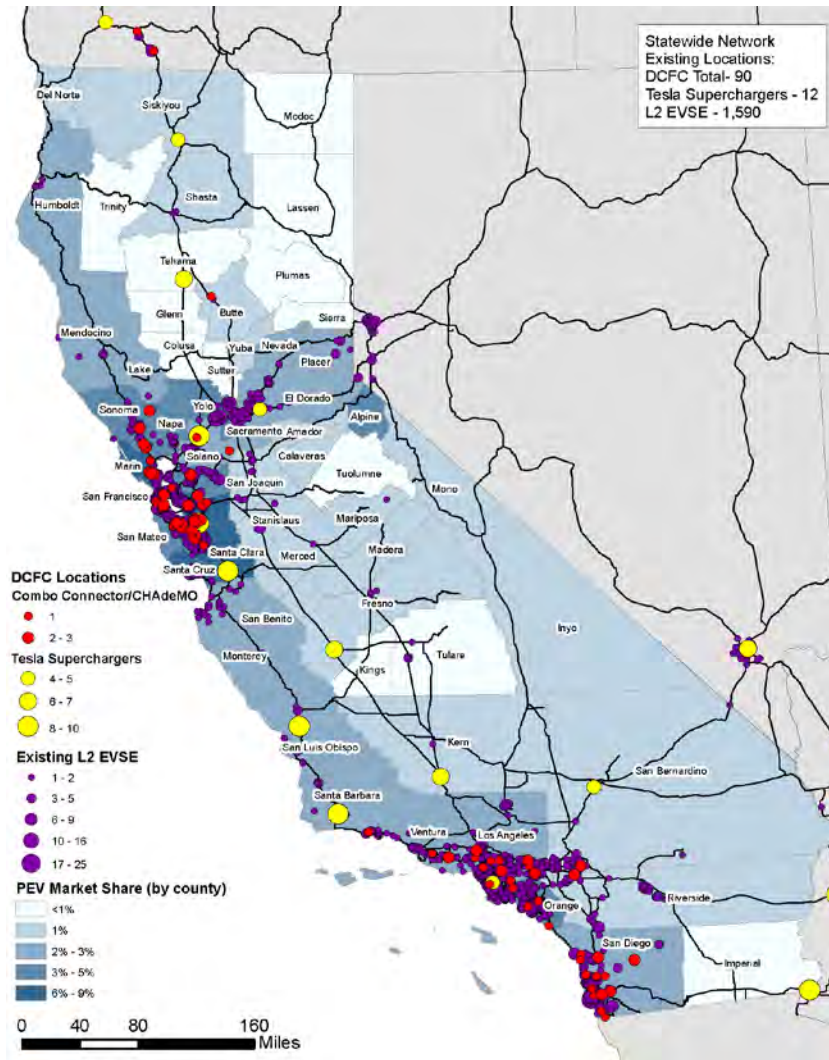


Figure 54: California USA – 2013 PEV Market Share

Source: (EPRI, 2013)

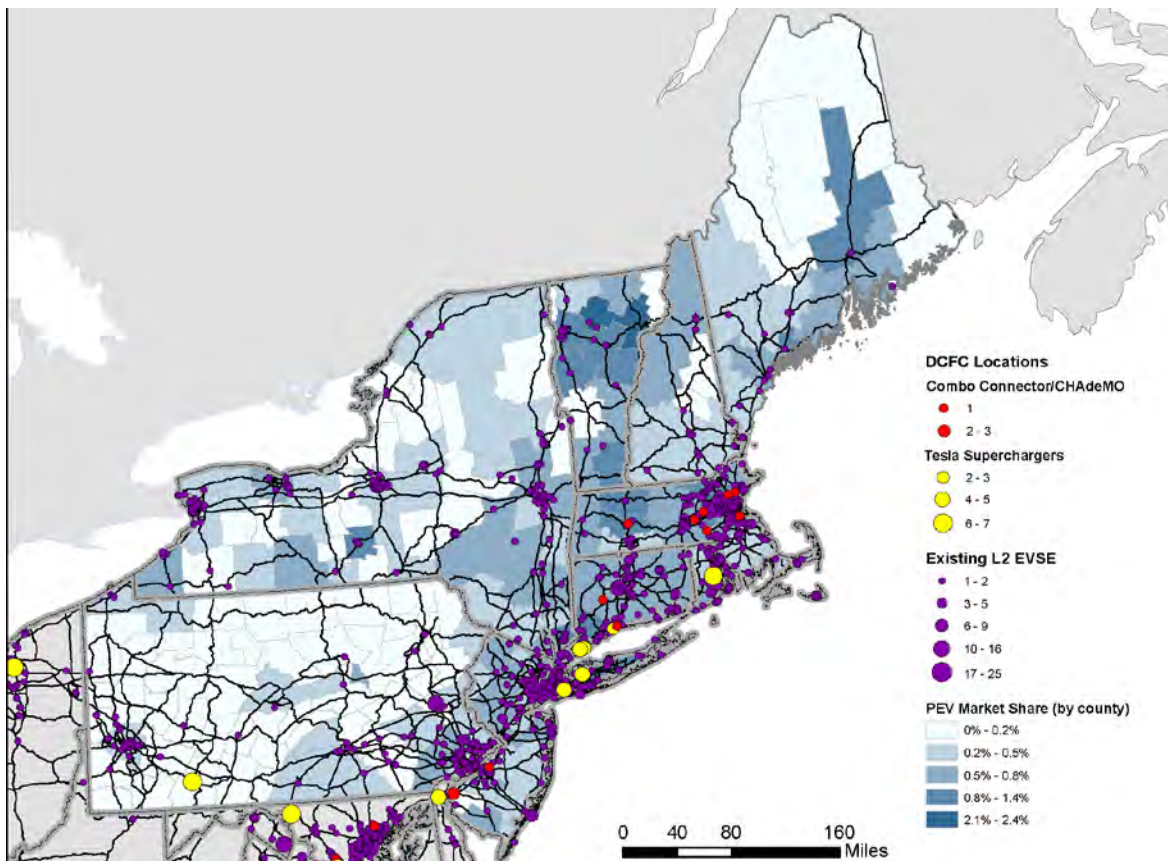


Figure 55: Northeast USA – 2013 PEV Market Share

Source: (EPRI, 2013)

Number of each type of publicly accessible charging station required

Figure 56 and Figure 57 give the number of charging events at publicly accessible charging points on or near the Interstate highway system, and at other publicly accessible charging stations (i.e., at local destinations). The number of each type of charging point depends on:

- The number of charging events per year (calculated in previous section).
- The number of charging events that might reasonably occur at each point per year.
- Having charging points in the locations where people want to use them.

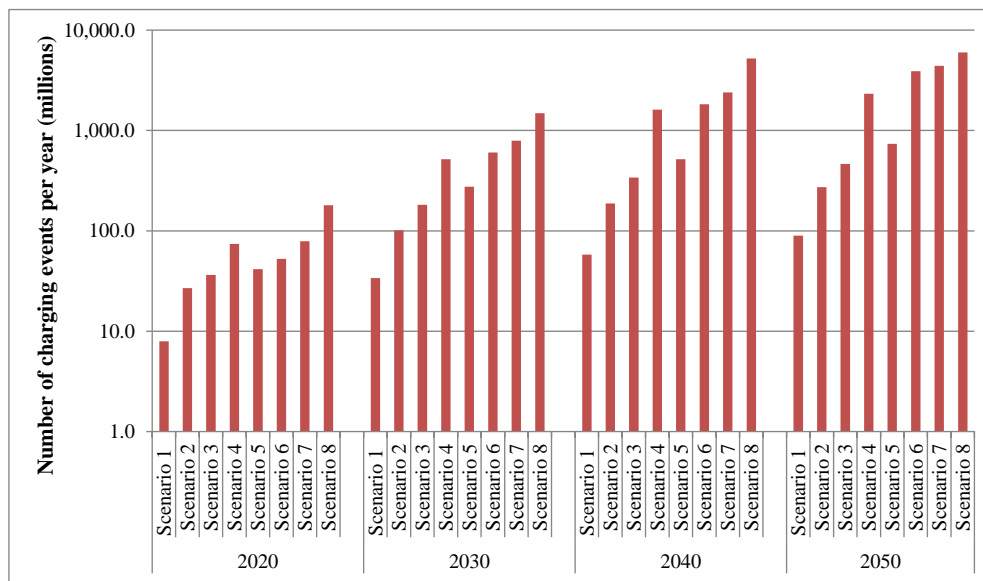


Figure 56: Number of charging events for non-Interstate highway (red) and publicly accessible charging points by scenario-year combination

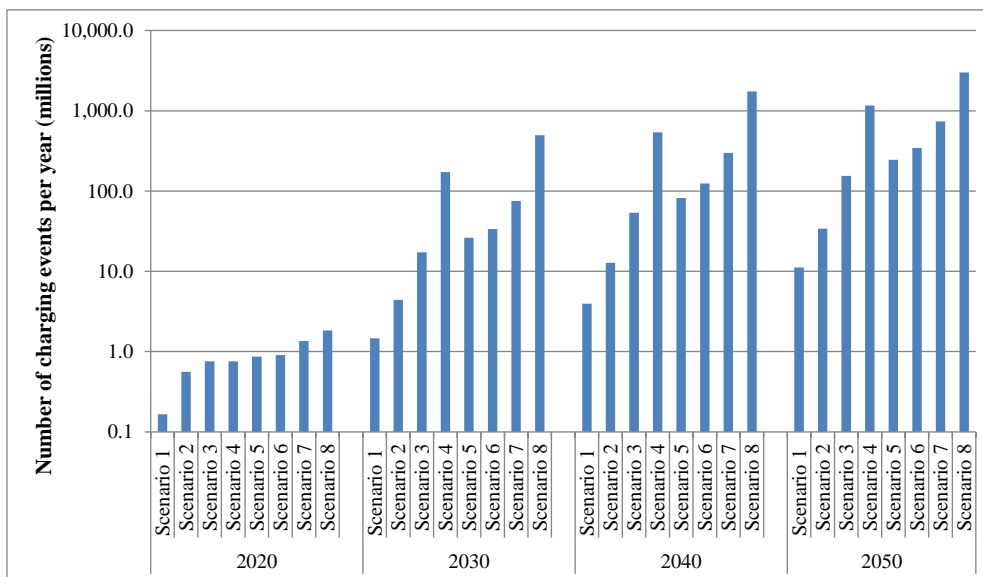


Figure 57: Number of charging events for Interstate highway blue and publicly accessible charging points by scenario-year combination

For non-Interstate publicly accessible highway charging stations, some guidance on the average number of charging events that might reasonably occur at each point per year can be gained from the Idaho National Laboratory reports to the U.S. Department of Energy Vehicle Technologies Program for the first two quarters of 2013 (see Appendix D: “Evidence used to support the assumptions made about charging characteristics at publicly accessible charging points”). These

reports describe the characteristics from approximately 2,500 publicly accessible Level 2 charging points and 80 publicly accessible DC Fast charging points. The reports indicate approximately 75 events per year for each AC Level 2 charging station, and 1,000 events per year for each DC Fast charging station. These numbers are used in this analysis for the 2012 analysis year.

For subsequent years, the average number of events projected to occur at each charging station increases linearly out to 2040, then remains constant through 2050. It is assumed that chargers are used for approximately 50% of the time between 7:00 a.m. and 11:00 p.m. (a 16-hour window). From this assumption, the maximum number of charging events that could occur within the 16 hours can be calculated.

For AC Level 2 charging in the future, it is assumed that the average charge transferred for each charging event is 10 kWh, sufficient to provide approximately 33 miles driving. At a charging rate of 7.5 kWh per hour, a 10kWh charge requires drawing power for 1.33 hrs. In the medium/long term, the average amount of time that a vehicle is connected to the charging station to attain this charge is assumed to be two hours. This corresponds to a maximum of eight events per day per charger between 7:00 a.m. and 11:00 p.m. (16 hours), and a maximum of 2,920 events per year.

For DC Fast charging in the future, it is assumed that the average charge transferred for each charging event is 20 kWh, sufficient to provide approximately 66 miles driving. At a charging rate of 50 kWh per hour, a 20kWh charge requires drawing power for 24 minutes. If faster charging rates are used—for example, 100 kWh per hour—it is assumed a proportionately higher charge is transferred and that charging also occurs for 24 minutes. In the medium/long term, the average amount of time that a vehicle is connected to the charging station to attain this charge is assumed to be 40 minutes, which corresponds to a maximum of 24 events per day per charger over a 16-hour period, and a maximum of 8,760 events per year.

From the estimations above, and the assumption that actual charger usage will be 50% of the potential maximum by 2040, the average number of charging events per charging station varies as shown in Table 37.

Table 37: Average numbers of charging events for publicly accessible charging station as a function of time

Battery charge type/ Year	2012	2020	2030	2040	2050
AC Level 2 publicly accessible charging station	75	500	1,000	1,500	1,500
DC Fast charger publicly accessible charging station	1,000	2,000	3,250	4,500	4,500

These are the numbers that are used to divide the total number of charging events for each PEV deployment scenario-year combination, to calculate the minimum number of charging station points required to meet PEV charging needs.

Consequently, for Scenario 8 in 2050, the 6 billion charging events for non-Interstate publicly accessible chargers (from Figure 56) would require approximately 4 million publicly accessible charging points. Estimates from one study for the number of off-street parking spaces in the United States ranged from 630–910 million, indicating that the required number of charge points would represent a small fraction of the total (Chester M et al, 2011). Nevertheless, installing approximately 4 million Level 2 charging points among these off-street parking spaces would present a very real deployment challenge.

In contrast, despite providing roughly the same amount of charge (see Figure 52), the approximately 3 billion charging events for Interstate publicly accessible chargers would require approximately 0.7 million publicly accessible charging points. Assuming 20 charge points at the average location, this would require approximately 35,000 charging locations used by travelers on or near the Interstate system. If these locations were evenly distributed, this would involve a charging location spaced at approximately every 1.4 miles of Interstate, which is implausible. Even if there were 140 charge points at the average location, there would need to be a charging location spaced at approximately every 10 miles of Interstate. These results suggest that the fraction of charging that would occur on or near the Interstate has likely been greatly overestimated.

The number of charging points required (based on scenario-defined charging requirements) is shown in Figure 58 and Figure 59. This is not directly proportional to the estimated number of required charging events, because the average number of charging events changes over time. In terms of locations, these would follow where the PEVs are used, so that in the early years (2020 and 2030), these charging events and charging points would be provided in locations with the fewest adverse climatic and topographical conditions, such as extreme cold and hot temperatures, and steep grades. During 2030–2050, the geographic distribution would be more evenly distributed as technological advances emerge to overcome the use of PEVs in such adverse conditions.

An alternative way of calculating the number of charging points required is to base it on PEV driver safety considerations. This method would involve a more extensive safety network of charging points available in the early years of deployment (to minimize the likelihood of drivers being stranded if they run out of charge), and the resulting network would be broader than one based solely on minimal charging requirements. This approach is the basis of the EPRI analysis discussed in Section 2.3.6. However, that analysis provided 99% of the U.S. population with charging station within 20 miles. The view of this research team is that Intercity corridors between dense PEV and charging station cities require about a 25–60 mile interval between stations.

3.5.4 Power provision for charging stations

3.5.4.1 Power to publicly accessible charging stations at local destinations: Shopping mall example

The total projected power needed at publicly accessible local charging stations was divided by the total number of shopping malls in the United States (108,000). This calculation showed that the average amount of charge supplied per charging area at each mall does not exceed 140 MWh²⁵ for any scenario prior to 2030. For 2040 and 2050, only Scenarios 4, 6, 7, and 8 exceed 140 MWh.

Since it is anticipated that 140 MWh per year is a small fraction of the total annual electricity consumption of a typical shopping mall, this analysis shows that there is likely already adequate capacity at shopping malls for PEV charging stations, for all scenarios out to 2030, and for the less aggressive deployment scenarios out to 2050.

3.5.4.2 Power to publicly accessible charging stations on or near the Interstate: Rest area example

It is estimated that there are nearly 2,700 rest areas on the Interstate highway system in the United States (restareas.appspot.com, Unknown). The number of charging points required to meet the demand for Interstate highway charging, assuming the use of DC Fast charging (shown in Figure 58 and Figure 59) can be divided by 2,700 to obtain some indication of the number of charging points required per rest area, as well as the amount of charge that would be supplied through the average rest area. For example, slightly more than 1,000 charge points would be required per rest area under Scenario 8 in 2050, which does not seem feasible and indicates that if the Scenario 8 deployment levels have been reached by 2050, additional locations would be required beyond rest areas alone.

²⁵ The 140 MWh per year is a figure that comes from the quantitative analysis of the charging infrastructure required. It is not a significant benchmark, but is quoted to give a quantification of average amounts of charge supplied per charging station charging area. To put this into some more every-day context, this is equivalent to the power consumption of eighteen 1500-watt microwave ovens operating continuously in the food court during the hours that a shopping mall is typically open.

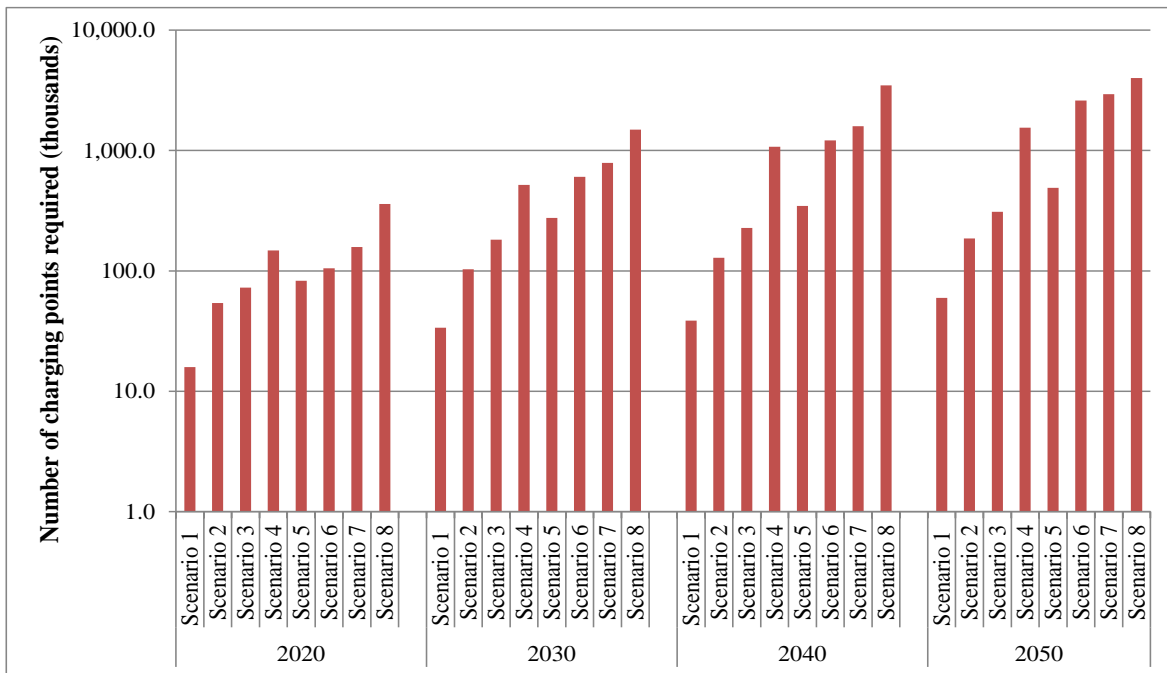


Figure 58: Number of publicly accessible charging points required by scenario for non-Interstate charging points

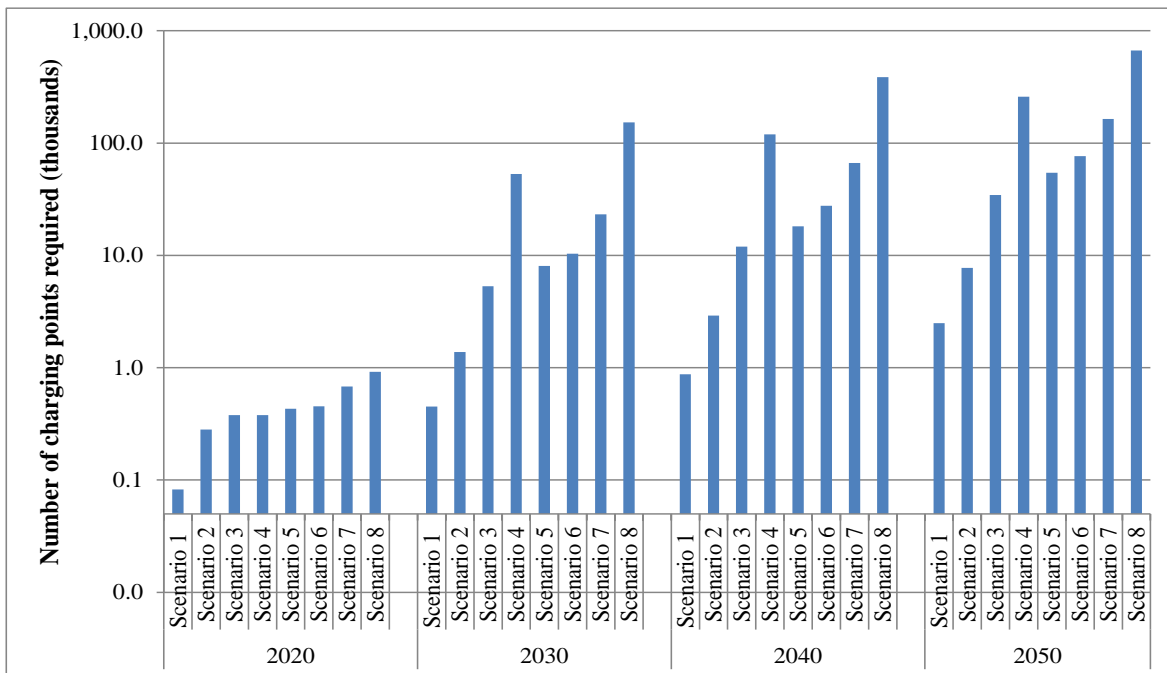
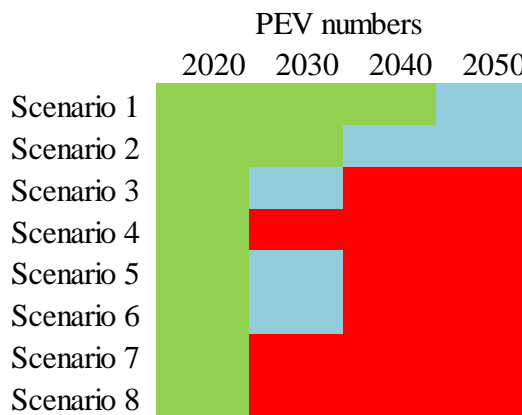


Figure 59: Number of publicly accessible charging points required by scenario for Interstate (blue) charging points

A study by the Illinois Center for Transportation on “green friendly” best management practices for Interstate rest areas concluded that average rest area power consumption is approximately 333 MWh per year (Illinois Center for Transportation, 2011)²⁶. The total projected power needed at publicly accessible Interstate charging locations for each scenario-year combination can be compared with this current average rest area power consumption, as shown in Figure 60. The total power supplied through Interstate charging points is divided by the assumed number of rest area locations (2,700). Green cells in the figure denote when the average PEV charge requirement per rest area is less than 33 MWh per year (10% of the average annual rest area power consumption), whereas red cells denote an average PEV charge requirement per rest area of more than 330 MWh per year (larger than the current average annual rest area power consumption). Blue cells correspond to an average PEV charge requirement per rest area between 33 and 330 MWh per year.

Figure 60: Matrix of the rest area electrical charging predictions for the different scenario-year combinations



Finally, enquiries with both Oregon DOT and Portland General Electric have indicated that three-phase power in (or even accessible to) rest areas is fairly rare. Even the largest rest area in Oregon did not have three-phase power until PGE installed it in anticipation of establishing charging stations. As noted earlier, many suppliers of DC Fast charging station require the presence of a three-phase supply.

²⁶ Table 1 on page 21 gives rest area power consumption as it is now. For 30 rest areas total = 10,000 MWh, i.e. average is approximately 333 MWh.

3.6 COST AND REVENUE ANALYSIS RESULTS

3.6.1 Costs for installing and using charging stations

3.6.1.1 *Current costs of charging stations*

Level 1 charging station: For AC charging, the function of the charging station is simply to establish a physical connection between the grid and the vehicle, and signify to the vehicle's on-board charger at what amperage to charge. For Level 1 charging (110 V AC and 15 A), a standard grid socket can be used, although the plug should be a three-pin plug—i.e., it should have a ground connection. Provided that there is an outlet sufficiently close to where the vehicle is parked, this can be a no-cost charging solution via an extension lead. A full battery charge using Level 1 charging station takes requires 10–20 hours of charge time.

Level 2 charging station: For Level 2 charging station, where the supply exceeds 15 amps and operates at 208–240V AC, the charging station equipment should be permanently connected to the grid rather than with plug and cord (National Electric Code Handbook, 2008). Typically, Level 2 charging station installations in homes will operate on a dedicated circuit with a dedicated fuse. The hardware costs for home Level 2 charging systems are now below \$500 (Bosch, 2013), and given the system's simplicity, may continue to decline in price. The cost of installation can vary. Plug In America (Plug In America, 2012a) quotes values between \$500 and \$2,500 for domestic Level 2 charger installation. Because installation is an inherently labor-intensive activity, the potential for cost reduction in this field may be more limited.

Level 1 charging is not anticipated for publicly accessible charging, because Level 2 is anticipated to be the lowest acceptable power transfer rate. All PEVs are equipped to use Level 2 charging, the charging rate of Level 2 is twice that of the Level 1 systems (allowing a battery to be fully charged in four to eight hours), and the cost of Level 2 charging station is not prohibitive. However, publicly accessible Level 2 charging will likely be located outdoors, resulting in higher hardware and installation costs compared to residential Level 2 charging station. Publicly accessible charging station may also require a billing system.

(ETEC, 2010) estimates the overall cost of purchasing and installing a publicly accessible Level 2 charging station with two outlets at \$15,000–18,000. A study of publicly accessible charging station installations in Houston, TX reports installation costs of between \$860 and \$7,400 (US Department of Energy, April 2012). Installation costs likely vary significantly depending on location-specific factors, such as the proximity of the charging station to an electricity supply at the required voltage.

DC Fast charging: DC Fast charging (Level 3) can provide 80 percent of a full charge in 15–30 minutes. The technology is more complex than Level 1 and 2 charging, as the process of converting AC from the grid into DC at the required voltage occurs within the charging station rather than within the vehicle. Moreover, the charging station needs to communicate with the vehicle's battery management system. Therefore, DC Fast chargers are more expensive than Level 1 and Level 2 charging station, although the costs appear to be falling significantly.

Several studies quote values in the range of \$25,000–60,000 per unit of DC Fast charging hardware. A recent estimate from an order of 48 units of 50kW Fast charging stations resulted in a cost of about \$16,500 per unit. However, this estimate does not include the cost of installation, which can be significant. For DC Fast charging, (Plug In America, 2012a) estimates installation costs, such as the cost of wiring, has a range of \$5,000–30,000 for installation, while (Fuji Electric, 2012) assumes about \$20,000.

Charging stations for the Tesla Supercharger program, which delivers higher energy transfer rates of up to 120 kW, are quoted to cost \$100,000–175,000. These stations can charge up to four vehicles simultaneously, so the per unit cost is about \$25,000–45,000. Figure 61 shows Tesla Model S cars at a Delaware SuperCharger location.



Figure 61: Tesla Model S cars at Delaware Supercharger location

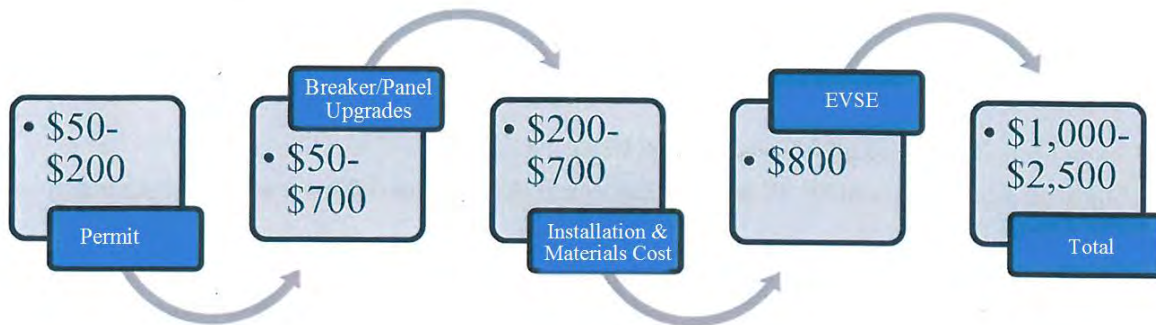
The cost of basic charging infrastructure increases with additional amenities, such as the construction of a canopy, as illustrated in Figure 62.



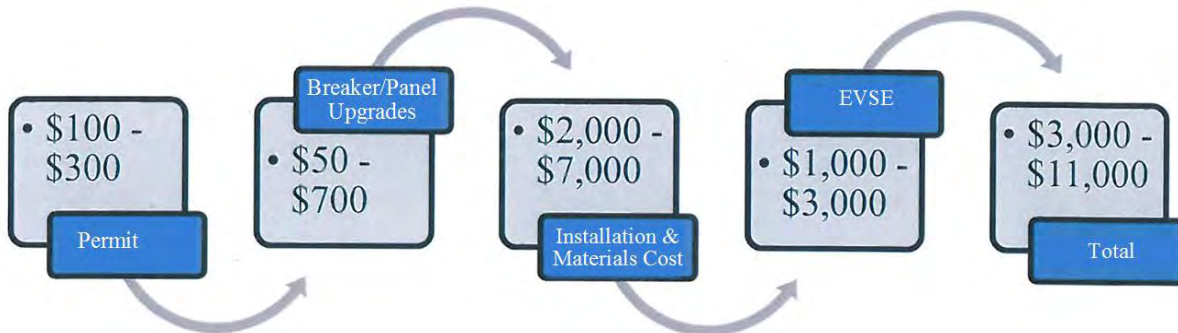
Figure 62: Tesla charging station with a canopy roof (Green Car Reports, 2013)

EVSE Cost Summary: U.S. DOE’s Clean Cities Program provided an estimated breakdown of the cost of various charging station components at a workshop in Los Angeles in May 2012. These costs are shown in Figure 63. The April 2012 Clean Cities Program “Plug-In Electric Vehicle Handbook for Public Charging Station Hosts” provides similar figures.

Residential charging station costs



Commercial Level 2 charging station costs



Commercial DC Fast charging station costs

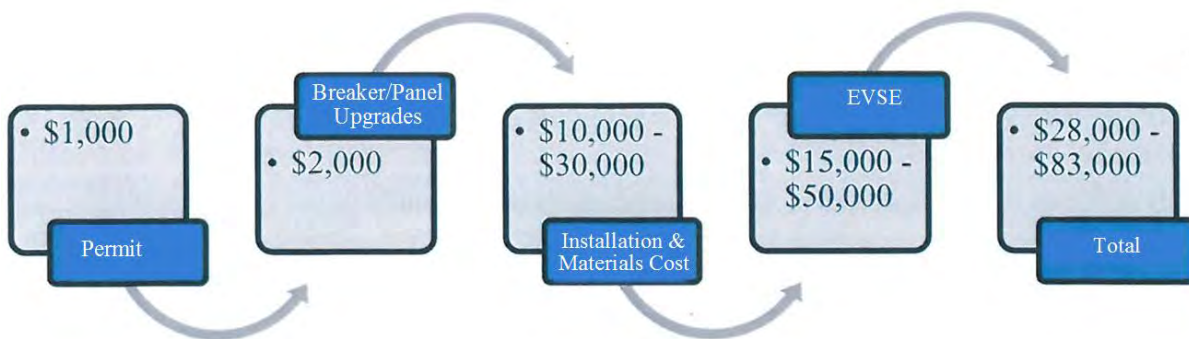


Figure 63: Breakdown of charging station costs for different installations

A summary of charging station cost estimates from a range of sources is given in Table 38. In addition to the up-front hardware and installation costs, there will also be ongoing operations and maintenance costs.

The scenarios analyzed in this project do not consider the use of federal funds to construct, maintain or operate PEV charging stations. Additional costs to the HTF are not anticipated, even with an aggressive FHWA program, as expenditures would normally be made by state DOTs (or local governments) from their apportionments under the Federal-aid Highway Program. An charging station project funded under CMAQ, for instance, would not generate additional costs. It would represent a decision by the state DOT (and MPO) to fund that project rather than another project (say, a traffic signal improvement) within its CMAQ apportionment.

Table 38: Summary of charging station cost estimates from various sources

Source	EVSE Type	Charger hardware cost low	Charger hardware cost high	Installation cost low	Installation cost high	Total cost low	Total cost high
(Plug In America, 2012a)	AC Level 1	\$100	\$500	\$100	\$500	\$200	\$1,000
(Plug In America, 2012a)	AC Level 2 Home	\$500	\$1,500	\$500	\$2,500	\$1,000	\$4,000
(Plug In America, 2012a)	AC Level 2 Commercial	\$2,000	\$6,500	\$3,000	\$5,000	\$5,000	\$11,500
(Plug In America, 2012a)	DC Fast	\$10,000	\$30,000	\$5,000	\$30,000	\$15,000	\$60,000
(U.S. Department of Energy, 2012c)	AC Level 2 Publicly accessible charging	\$1,000	\$3,000	\$2,000	\$8,000	\$3,000	\$11,000
(U.S. Department of Energy, 2012c)	DC Fast Publicly accessible charging	\$15,000	\$50,000	\$23,000	\$33,000	\$28,000	\$83,000
(ETEC, 2010)	AC Level 2 Publicly accessible charging	-	-	-	-	\$15,000	\$18,000
(ETEC, 2010)	DC Fast Publicly accessible charging	-	-	-	-	\$65,000	\$70,000
(Fuji Electric, 2012)	DC Publicly accessible Fast charging	\$25,000	\$60,000	\$20,000	\$20,000	-	-

Source	EVSE Type	Charger hardware cost low	Charger hardware cost high	Installation cost low	Installation cost high	Total cost low	Total cost high
(Inside EVs, 2013)	DC Publicly accessible Fast charging	\$16,500	-	-	-	-	-
(techcrunch.com, 2013)	Tesla Fast charging station	-	-	-	-	\$25,000	\$50,000

3.6.1.2 Future costs of charging stations

The costs described above are likely to decline in the future, both due to economies of scale (of mass production and installation) and the benefits of learning from experience. There have been claims in the press that a \$100 residential Level 2 system may shortly become available (Kickstarter.com, 2013).

In order to assess the potential future cost of more widespread publicly accessible charging station, current street lighting costs can be assessed as a comparison. The total cost of installing one street light inclusive of material and installation cost is approximately \$4,000 (My LED Lighting Guide, 2013). In the longer term, the cost of a publicly accessible charging station could fall below that value, as a charging station would tend to require less heavy installation equipment than street lighting.

Challenges exist that could limit the potential for economies of scale to yield cost reductions. For example, siting publicly accessible charging station in remote areas along the Interstate highway system will likely continue to be relatively expensive, due to the remoteness and the cost of installing a suitable grid supply. These costs could be mitigated by technological advances in off-grid electricity production (e.g., wind or solar power) and energy storage, which could provide increased reliability and overcome the need to extend the grid supply (cleantechnica.com, 2013).

3.6.2 Revenue impacts associated with PEV deployment

CAFE and GHG standards being phased-in through model year 2025 will reduce per-mile consumption of motor fuels. In the absence of offsetting increases in total miles traveled, this phasing-in of CAFE standards will lead to a reduction in motor fuel tax receipts. PEVs are one of the many strategies that manufacturers may use to meet the fleet-average CAFE and GHG targets. However, the extent to which PEVs will contribute to the overall targets is uncertain, as discussed in Section 3.6.2.4. This report uses the eight scenarios to illustrate the range of impacts that may result from deployment of PEVs in the context of the overall standards.

The portion of PEV travel that is powered by electricity (all travel, in the case of BEVs) does not generate any motor fuel tax receipts. A concern exists that these vehicles are not “paying their fair share” of user fees to support the ongoing construction and maintenance of the U.S. highway network. Section 3.6.2.6 suggests some strategies to address this disparity.

3.6.2.1 Current motor fuel tax levels

Federal motor fuel tax: The Highway Trust Fund (HTF) is a transportation fund that receives money directly from a federal motor fuel tax. The current rates of motor fuel tax are 18.4 cents per gallon on gasoline and 24.4 cents per gallon on diesel fuel (Congressional Research Service, 2012, EIA, 2013c). The federal tax on motor fuels yielded \$34.15 billion in 2012 (Tax Policy Center, 2013). This tax was first imposed by the federal government in 1932, and rose to the current level of 18.4 cents per gallon in October 1993. In 1996 and for most of 1997, there was a 21-month period when the tax was reduced to 18.3 cents a gallon because the “Leaking Underground Tank Trust Fund” expired, but this fund was then reinstated. During the 20-year period in which the motor fuel tax has remained unchanged, inflation has raised the consumer prices index by about 60% (US Inflation Calculator). Because the fleet-average vehicle fuel economy was relatively flat over much of this period, the tax revenue generated per mile of vehicle travel fell significantly in real terms during this time. (The Highway Construction Cost Index provides a more accurate measure of highway-related costs than does CPI, has although it still reflects that such costs have increased by approximately 50% from 1993 (FHWA, 2013b, FHWA, 2013a).).

State and local motor fuel taxes: In addition to the federal motor fuel tax, individual states impose their own state motor fuel tax, as do some local jurisdictions. Figure 64 shows the combined federal and state gasoline tax (in cents per gallon) superimposed on a map of the United States (API, 2013).

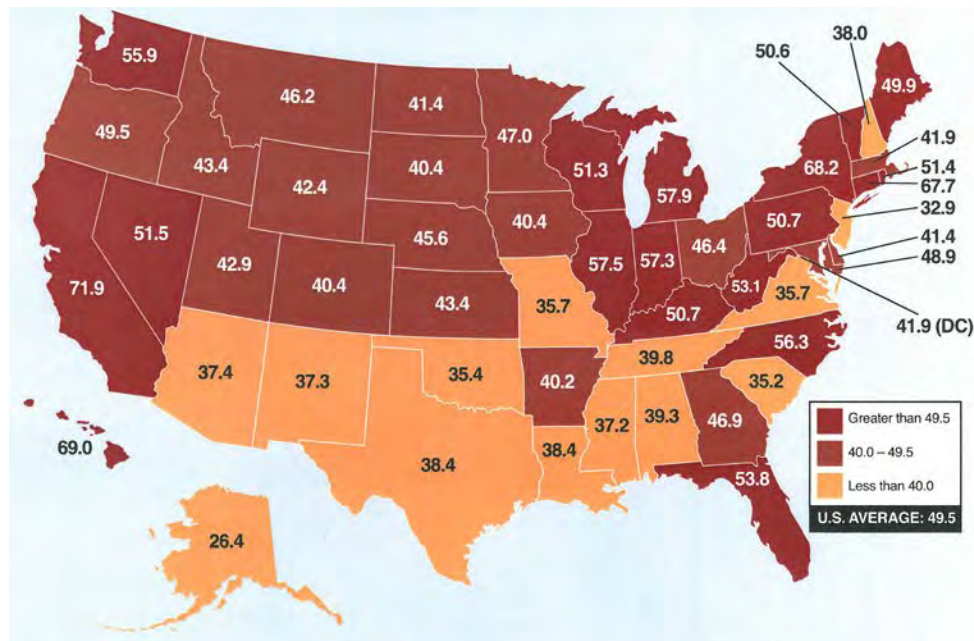


Figure 64: The combined federal, state, and local gasoline taxes in July 2013 (from API)

State gasoline taxes (state excise tax plus other taxes/fees) vary, from less than 10 cents per gallon in Alaska, to approximately 50 cents per gallon in California and New York. Additionally, local governments may also have taxes on fuel. This report only considers the federal tax implications of PEVs.

3.6.2.2 Revenue impact analysis methodology

This research includes an objective analysis of the implications of different PEV deployment scenarios on HTF revenue, in order to suggest ways in which the resulting reduction in revenue could be addressed in the future. The analysis does not evaluate the corresponding impact on lost state and local motor fuel tax revenues, although it should be noted that these are larger than the federal tax.

This analysis assumes that the PEV scenarios displace only gasoline. We ignore any displacement of diesel fuel because of the very low percentage of light-duty diesel use in the United States. (see Section 3.4.1.4).

The analysis builds on the earlier quantitative analysis, and for each scenario calculates the reduction in gas tax revenue based on the volume of gasoline displaced by PEVs in the U.S. light vehicle fleet over-and-above the gasoline savings mandated by the CAFE standards (see Section 3.4.1.4), using the equation below.

$$\text{Gas tax reduction} = \text{The displaced amount of gasoline} \times \text{the gas tax per gallon}$$

Figure 65: Equation for reduction in gas tax revenue

The gasoline displaced for the various PEV deployment scenarios (as given in Table 35) is calculated relative to AEO 2013 projections of gasoline consumption. AEO 2013 gasoline consumption corresponds to the very limited PEV deployment in Scenario 1, considered the reference scenario (the baseline or “business as usual”) for the revenue analysis. An advantage of using the projections given in AEO 2013 is that this baseline case also considers the impacts of current legislation on gasoline sales, including the CAFE and ZEV standards out to model year 2025. These drivers for improvements in vehicle fuel efficiency will also reduce HTF revenues. Analysis of the increasing average mpg figures in AEO enables the calculation of the impact of ICE efficiency improvements on HTF revenues, and comparison of that impact to the impact of PEV deployment (see Section 3.4.1.4).

The 2010 on-road gasoline and diesel consumption given in AEO 2013 is converted from quadrillions of Btu (the AEO 2013 units) into gallons of gasoline and diesel. The 18.4 and 24.4 cents per gallon federal tax rates for gasoline and diesel are then applied, respectively, to obtain the federal motor fuel tax revenue from projected transportation fuel use.

3.6.2.3 Baseline HTF revenue with implementation of CAFE program

Table 39 shows the projected fuel consumption figures given in AEO 2013 (EIA, 2013a) . The table has three sections. The first section tabulates the projected transportation energy supply by motor gasoline and on-road diesel as specified in AEO 2013, in units of quadrillion Btus. The second section converts the energy use into fuel volume, listing the millions of gallons of fuel projected to be used. The third section gives the federal motor fuel tax revenue for these levels of fuel use, assuming the current rates of motor fuel tax of 18.4 cents per gallon of gasoline and 24.4 cents per gallon of diesel.

Table 39: Projected transportation energy use, and resulting motor fuel tax revenues

Projected transportation energy use (quadrillion Btus) from AEO 2013							
Fuel type/ Year	2010	2015	2020	2025	2030	2035	2040
Motor gasoline	16.791	15.393	14.883	13.856	13.057	12.691	12.643
On-road diesel	5.818	6.781	7.281	7.519	7.613	7.727	7.900

Projected transportation fuel use (million gallons)							
Fuel type/ Year	2010	2015	2020	2025	2030	2035	2040
Motor gasoline	144.64	132.59	128.20	119.35	112.47	109.32	108.91
On-road diesel	45.30	52.79	56.68	58.53	59.27	60.16	61.50

Federal motor fuel tax revenue from projected transportation fuel use (\$ billions)							
Fuel type/ Year	2010	2015	2020	2025	2030	2035	2040
Motor gasoline	26.61	24.40	23.59	21.96	20.69	20.12	20.04
On-road diesel	11.05	12.88	13.83	14.28	14.46	14.68	15.01
Total	37.67	37.28	37.42	36.24	35.16	34.79	35.05

The overall total is the baseline HTF revenue from motor fuel tax, given these assumptions. The anticipated federal motor fuel tax revenue is shown graphically in Figure 66.

By way of validation, the 2010 HTF revenue estimate developed using this approach can be compared to actual figures provided by the Tax Policy Center. The above calculation using the AEO 2013 data resulted in 2010 HTF income of \$37.67 billion, which is 99.5% of the figure provided by the Tax Policy Center. This very close agreement lends support to this analysis and its projected incomes, which are consistent with the projected fuel use as described in AEO 2013 and Scenario 1.

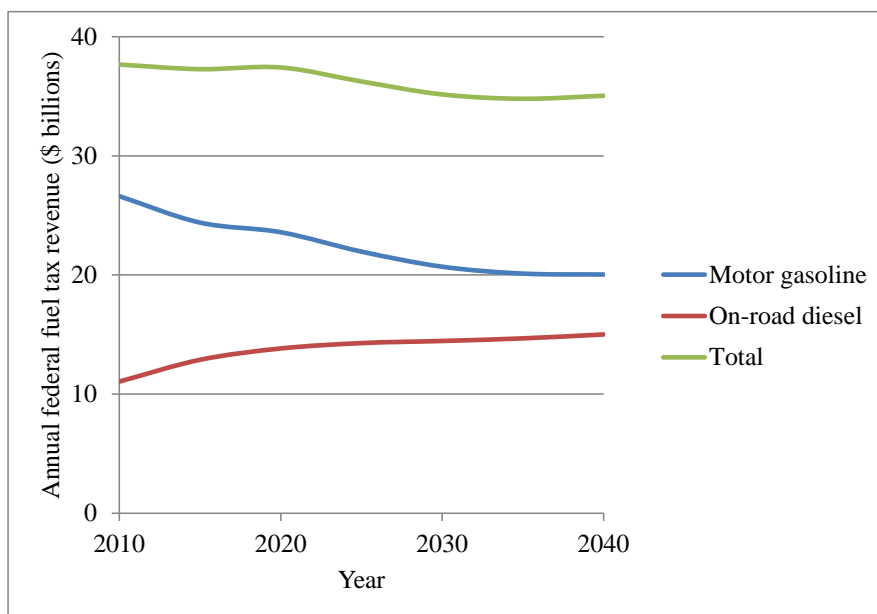


Figure 66: The federal motor fuel tax revenue from projected transportation fuel usage (EIA, 2013a)²⁷

3.6.2.4 Impact due to CAFE

The AEO 2013 projections of gasoline consumption incorporate the projected reduction in gasoline use in future years caused by the increasing impact of the CAFE standards. AEO 2013 also makes assumptions regarding vehicle numbers and VMT to project future gasoline consumption. However, if ICE fuel efficiency remained at the 2012 level (rather than improving, as is required by CAFE) then gasoline consumption would be higher than the AEO 2013 projection.

The difference between the volume of gasoline calculated using the “2012 constant fuel efficiency” and the projected volume of gasoline in AEO 2013 allows us to estimate the reduction in HTF revenue caused by the CAFE program. This estimated reduction is presented in Figure 67. The chart goes through to 2040, which is the upper limit of the AEO 2013 projections.

The losses of HTF revenue due to improvements in light-duty vehicle efficiency caused by the introduction of the CAFE standards are considerable—approximately \$12 billion in 2040—reducing HTF revenue to approximately \$35 billion in 2040, as shown in Figure 66.

²⁷ The bases for this projected federal tax revenue are road transport fossil fuel usage as projected to 2040 in AEO 2013.

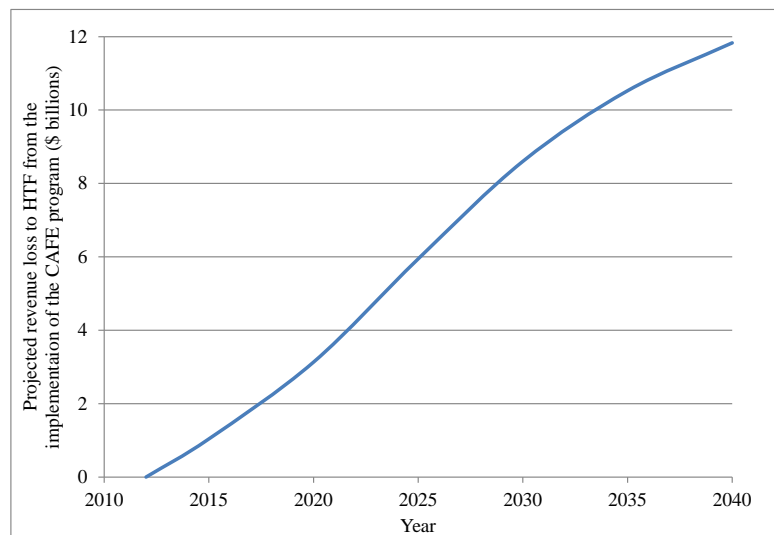


Figure 67: The reduction in HTF revenue relative to a constant 2012 level of ICE fuel efficiency

3.6.2.5 Impact of PEV deployment scenarios on HTF revenue

Overall impact of PEVs: The overall impact of PEVs on HTF revenue cannot be considered separately from the impact of the CAFE standards. In this analysis, two cases are considered.

1. The first case presumes that CAFE standards taking effect out to 2025 will be met with only a minimal level of PEV deployment. After 2025, more fuel-efficient models will continue to be sold, and the light vehicle fleet will continue to become more efficient as older, inefficient vehicles are retired and replaced by new models that meet the 2025 efficiency requirements. In this case, the increasing deployment of PEVs, which occurs at an accelerated rate after 2025, leads to an additional reduction in gasoline sales beyond that resulting from CAFE standards. For this to be the case, it is also assumed there is no change in the average fuel economy of new ICE vehicles after 2025, even though the increased PEV sales would allow the introduction of less efficient vehicles without breaching the CAFE requirements.
2. The second case presumes that CAFE standards will be met using all the compliance credits resulting from PEV deployment. Consequently, up to 2025, increasing PEV sales help mitigate the need to improve ICE vehicle fuel efficiency. After 2025, the increasing deployment of PEVs causes ICE vehicle average fuel economy to decrease (because the increased PEV sales enable less efficient vehicles to enter the fleet without CAFE requirements being breached).

For the first case, the baseline deployment scenario described in AEO 2013 predicts a reduction in gasoline sales due to CAFE standards, and the incremental deployment of PEVs for the scenarios presented are **additional** fuel efficiency improvements, beyond those due to CAFE.

This additional improvement leads to further reductions in gasoline sales. **These are the reductions calculated in this report.**

For the second case, the reduction in gasoline sales caused by the deployment of PEVs is offset by an increase in gasoline sales caused by ICE vehicles becoming less fuel-efficient than they otherwise would under CAFE requirements. **For this case, the net change in gasoline sales is zero.**

Actual gasoline sales impacts will likely fall somewhere between the two extremes described by the two cases above, although the precise number of CAFE credits that will be generated by PEVs under the different deployment scenarios is unknown. **Therefore, the impact of PEV deployment on HTF revenue is a possible range from zero to the maximum values calculated and reported herein.**

The maximum impact of PEV deployment on HTF revenue is quantified by considering how much electricity PEVs use in a year, the equivalence to gallons of gasoline displaced, and the assumption that all the displaced gasoline leads to reduced gasoline sales rather than contributing to CAFE fuel efficiency improvements. As discussed earlier in Section 3.4.1.4, based on assumptions about the mobility equivalence of electricity and gasoline for vehicles available in 2012, an average 13 kWh is considered equivalent to one gallon of gasoline for all PEVs in 2012. Future equivalence is estimated based on the anticipated change in efficiency of electric vehicles, detailed in Table 34, and the anticipated change in efficiency of ICE vehicles caused by the CAFE regulations and within the AEO 2013 projections of future gasoline use. Additional details are given in Appendix C: “Evidence used to define the average number of kWh required to displace a gallon of gasoline.”

The amount of electric power consumed by the PEV fleet, shown in Figure 46 and Table 33, can be converted into the volume of gasoline not used by the U.S. light vehicle fleet because of VMT by PEVs for each scenario (shown in Figure 48). If it is assumed that all the vehicle fuel displaced is gasoline, and that the federal motor fuel tax rate of 18.4 cents per gallon applies, then the maximum reduction in federal motor fuel tax collected can be calculated for each PEV deployment scenario.

The eight PEV deployment scenarios define six different rates of PEV VMT. The PEV deployment numbers for three sets of these scenarios originated from previously published analyses, as summarized below:

- Scenario 1, based on AEO 13.
- Scenarios 5 & 6, based on EPRI medium-growth projection.
- Scenario 8, based on EPRI fast growth projection.

The PEV deployment numbers for the intermediate scenarios were chosen to provide relatively even growth steps, as shown in Table 35.

The maximum revenue impacts of the three sets of scenarios listed above are shown in Figure 68. Solid lines are the revenue impacts based on 13 kWh displacing a gallon of fuel, as discussed in Section 3.4.1.5, and as shown in Figure 48. Upper and lower broken lines are a sensitivity analysis for each of the three scenarios based on equivalency factors of 9 kWh and 17 kWh. The rationale for these upper and lower bounds is discussed in Section 3.4.1.5. The revenue impacts for all eight scenarios are tabulated in Table 40.

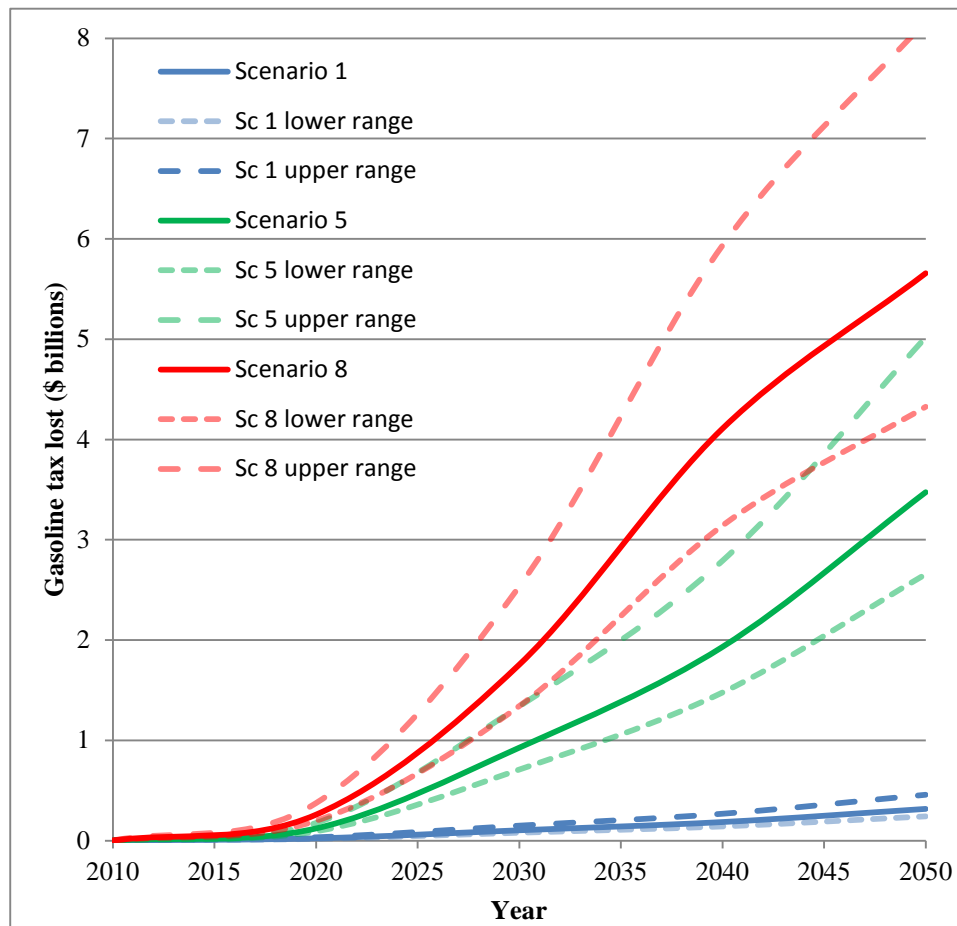


Figure 68: Maximum reduction in annual federal motor fuel tax revenue caused by electric PEV travel by scenario

Table 40: Maximum reduction in annual federal motor fuel tax revenue caused by electric PEV travel by scenario (billion dollars)

Scenario	Scenario prediction	2010	2020	2030	2040	2050
Sc 1	Baseline	0.002	0.023	0.104	0.186	0.317
Sc 2	Modest additional growth	0.002	0.079	0.312	0.603	0.966
Sc 3	Larger additional growth	0.002	0.107	0.611	1.269	2.193
Sc 4	Larger growth & Interstate highway charging	0.002	0.107	0.611	1.269	2.193
Sc 5	Based on EPRI medium growth	0.002	0.122	0.927	1.932	3.474
Sc 6	Based on EPRI medium growth and extended range	0.002	0.128	0.951	1.954	3.250
Sc 7	Larger growth than Sc 6	0.002	0.192	1.332	2.820	4.170
Sc 8	Based on EPRI high growth, extended range & highway charging	0.002	0.260	1.755	4.108	5.657

The maximum reduction in federal motor fuel tax revenue caused by PEV VMT for Scenarios 1–6 to 2040 leads to less than \$2 billion reduction in gasoline tax revenues per year. \$2 billion represents a reduction in total revenue of approximately 5% relative to the reference scenario (baseline or “business as usual”). The largest reduction—the reduction due to Scenario 8 in 2050—represents a reduction of approximately 16% relative to the reference scenario.

As noted at the start of this section, the actual impact of increased PEV deployment may lead to some reduction in federal motor fuel tax revenue by a figure within the range of zero (if all the PEV deployment is used to meet the CAFE standards) to the maximum figures presented in Table 40. **Even at the highest deployment levels, the motor fuel tax impacts of PEVs are a relatively small fraction of the overall impact of the CAFE program.**

3.6.2.6 Alternative revenue schemes for mitigating the impact of revenue losses due to PEV deployment

The previous section detailed the estimated reduction in federal motor fuel tax revenues attributed to each scenario over time. While the magnitude of the impact varies, some of the scenarios represent a significant enough impact to warrant mitigation, and consequently, FHWA may wish to consider alternative revenue schemes. In addition to addressing possible reduced revenues, this would also allow FHWA to respond to possible concerns about the perceived lack of equity of some transportation system users not “paying their fair share.”

Options for addressing the revenue losses attributable to PEVs fall into three general categories, each of which would require federal legislation:

- Option A: Increase the motor fuels tax.

- Option B: Levy a PEV excise tax.
- Option C: Levy a mileage tax.

Option A: Increase the motor fuels tax: One method to address the reduced motor fuels tax revenue caused by increased PEV use would be to increase the federal motor fuels tax commensurately. Meeting the projected 2020 shortfall would require a motor fuels tax increase of between 0.02 cents (i.e., two hundredths of one cent, or \$0.0002) per gallon for Scenario 1 (which would replace the projected \$23 million in lost revenue) and 0.21 cents per gallon (\$0.0021) for Scenario 8 (which would replace the projected \$260 million in lost revenue).

In practice, of course, any tax increase addressing PEV revenue loss would very likely be part of a much broader initiative addressing both overall revenue losses (for example, due to CAFE standards and lack of gas tax purchasing power due to inflation) and the very significant costs of bringing the nation's legacy transportation infrastructure to a state of good repair and beginning to build a 21st century transportation system. Although revenue losses due to PEVs might not figure prominently in what would likely be a tempestuous debate on any major fuels tax increase, the issue of "equity" could play a role. The findings presented above are consistent with those in a recent paper by the Congressional Research Service (Congressional Research Service, 2013), which generalizes that "adding a penny to federal motor fuels taxes provides the trust fund with between \$1.6 billion and \$1.8 billion in new annual revenue."

Option B: Levy a PEV excise tax: Compared to ICE vehicles, PHEVs pay less motor fuels tax, and BEVs pay none. In legislative debates at the state level, advocates of increased revenues have found it prudent to argue that PEV owners should pay their "fair share" of transportation user fees. Some states have looked at various ways of taxing PEVs, both to address revenue losses and to maintain an appearance of equity. One of the best known PEV tax initiatives was developed in the State of Washington, where the legislature levied a \$100 annual tax on PEVs, to be paid along with the vehicle's annual registration fee. Thus far, only Virginia has enacted a similar fee.

While it seems paradoxical to tax PEVs through one mechanism while subsidizing them through another, the "fair share" argument appears to be strong enough in some quarters to make the approach seem reasonable. The federal government has no statutory authority or obvious mechanism to charge a similar annual PEV fee, so a new excise tax system would need to be devised. Using—again—a hypothetical near-term surface transportation reauthorization bill, meeting the projected 2020 shortfall would require an annual excise tax of \$25.60²⁸ per PEV per year for Scenario 1 (assuming 0.9 million PEVs on the road), up to \$32.50 per PEV per year for Scenario 8 (assuming 8.0 million PEVs on the road). Imposition of a PEV excise tax would again presumably be included in a broader revenue package. In addition to potentially resolving the equity issue, imposition of a PEV fee could strengthen the case for making PEV charging infrastructure more widely eligible for funding through the federal-aid highway program.

²⁸ Values are in current U.S. dollars (USD), calculated using AEO 2013 data and 2013 motor fuel tax rates.

Option C: Levy a mileage tax: The strategy of replacing a tax on motor fuels with a tax on miles driven (variously called a mileage tax, road user fee, or mileage-based user fee) as the mainstay of transportation funding has been a subject of discussion among policy makers, academics, and transportation professionals for several years. The idea reached prominence with the report of the National Surface Transportation Infrastructure Financing Commission in 2009, which concluded:

Direct user charges in the form of mileage-based user charges are the most viable and sustainable long-term “user pay” option for the federal government to raise adequate and appropriate revenues to provide the federal share of funding for the system. Both real-world examples and academic research demonstrate that VMT fee systems have the capacity not only to raise needed revenues but also to provide additional benefits, including more efficient use of transportation infrastructure, reduced environmental and social externalities, and ancillary benefits to users in the form of information for drivers. Critically, a VMT fee system is the only option the Commission evaluated that, in addition to raising revenues, could actually reduce the amount of necessary additional capacity by improving the efficiency of current capacity use. (National Surface Transportation Infrastructure Financing Commission, 2009)

Under a flat mileage tax system, all light vehicles—regardless of motive power—would pay the same rate. This flat rate would avoid any revenue reduction caused by increasing PEV proliferation and would also provide clear “equity” for all system users. However, this system could also be considered to discourage not only PEVs, but smaller and more fuel-efficient vehicles more generally. A fuels tax, despite its possible shortcomings, provides a rough incentive for fuel economy improvement. Two approaches have been suggested for dealing with the “incentives” issue. Some mileage tax advocates argue that all transportation system users should pay the same user fees, and that policy incentives and disincentives to encourage certain behaviors should be implemented separately. Another approach would be to impose variable rates—such as for time of day (congestion pricing), vehicle weight, or rural driving.

A mileage tax may not be easily enacted in the near future, due to a number of technical and implementation issues, some of which were presented in a 2012 report by the Regional Plan Association (Regional Plan Association, 2012), including:

- **Transitional issues** – Should a mileage tax be phased in? Should it have an “opt-in” feature? Should it apply to some categories of vehicles first? Should it only be introduced after manufacturers install new mileage detection units?
- **Collection costs** – The motor fuels tax requires only about 1 percent of gross revenue for administrative costs, while costs for administering a mileage tax are likely to be much higher. Can costs be reduced to acceptable levels?
- **Unresolved technical issues** – These issues include the various ways to track and record vehicle miles traveled and the transmission of that data for tax collection purposes.

- **Equity** – To what extent will a mileage tax be viewed as a regressive tax, and how can that problem be addressed?
- **Public opposition** – A mileage tax potentially faces very strong public opposition, largely due to concerns related to protection of privacy and government intrusion. Evidence of the depth of this opposition can be seen in a report by the National Capital Region Transportation Planning Board, which conducted an in-depth public workshop on transportation finance, including presentation of a comprehensive mileage tax scheme.

The objections to this scenario were visceral. Participants found the proposal overwhelming and unfamiliar, they thought it would be impossible to implement, and they were concerned about where the money that was raised would go. The scenario provoked a sense of outrage regarding issues of privacy and government overreach. The phrase “big brother” was repeated frequently. Many comments reflected a general sense of disbelief: “You’re going to charge me just to go to the grocery store?” Some people said that the scenario would restrict movement in a way that was “un-American.” Some participants expressed a sense of being gouged: they felt the proposal would be taking advantage of the fact that people have no choice but to drive. (National Capital Region Transportation Planning Board, 2013)

A mileage tax could potentially be applied to PEVs only. Mileage tax proponents have proposed this at the state level (notably in Oregon) as a way of “piloting” a broader use of the mileage tax. According to C2ES’s report “A Guide to the Lessons Learned from the Clean Cities Community Electric Vehicle Readiness Projects,” Colorado, Kansas City, North Carolina, Ohio, and Oregon are each involved in developing road user fees. Hawaii and South Carolina have subsequently announced their consideration of new mileage tax bills (C2ES, 2014b). A recent bill under consideration in the Oregon legislature would set the mileage rate for EVs at 1.56 cents per mile. Oregon ultimately adopted a pilot “opt-in” VMT program that is independent of the fuel type used by vehicles. The idea of a pilot is a suggestion that has been picked up in a recent Government Accountability Office report, whose authors recommend that:

Should Congress wish to explore mileage fees as a mechanism for funding surface transportation, it should consider establishing a pilot program to evaluate the viability, costs, and benefits of mileage fee systems for [commercial trucks and] electric vehicles – to develop a mechanism through which the owners of these vehicles can contribute to the Highway Trust Fund for their use of the nation’s roadways. (United States Government Accountability Office, 2012)

Unresolved technical issues remain a current obstacle, yet developments in vehicular telematics and on-board diagnostic-based aftermarket devices indicate a pathway to mileage tax implementation. This opportunity surfaced as a main theme in order to overcome public acceptance issues at the Fifth Annual Symposium on Mileage-Based User Fees held in 2013. At the conference, Nevada DOT (NDOT) also shared the public’s concerns around being tracked

via GPS, although most drivers NDOT surveyed are open to a simple on-board diagnostic (OBD) device that does not collect location information.

According to the analysis presented at the symposium, a decline in gasoline consumption will translate to a 37 percent drop in gas tax revenues by 2016 and a projected 60 percent decline in revenues by 2025. The scenario analysis demonstrated that if a mileage tax were implemented in 2016, a 100 percent increase over the projected fuel tax revenue could be realized, with a 300 percent increase by 2025 (Baker, 2013).

4 RECOMMENDED PATHWAYS FOR FHWA, STATE DOT AND OTHER TRANSPORTATION AGENCY ACTION

As discussed earlier, the research team developed eight scenarios of potential PEV deployment to demonstrate a range of potential outcomes, to which FHWA may wish or be called upon to respond. The range of potential outcomes covered the numbers of PEVs, the fraction that are BEVs, their range, and potential vehicle charging behavior. The eight scenarios represent different credible rates of deployment with data and analysis provided for 2020, 2030, 2040, and 2050. Each scenario-year combination represents a snapshot of deployment characteristics that FHWA may wish to consider.

Drawing upon the analysis of the eight scenarios, the research team proposes in this chapter three pathways for FHWA, State DOT, and other transportation agency action. The pathways suggested are additive, in that the second and third responses levels are additional to the first level. The minimum response level we name **Market Response**. This pathway represents catching up to the PEV market activity so that transportation agencies do not become an impediment to the advancement of the technologies. The second pathway we call **Market Support**. This pathway involves a more active effort by FHWA and state and local agencies to deliberately keep pace with the deployment of vehicles and charging stations. The most aggressive of the pathways we name **Market Acceleration**. This set of activities goes beyond supporting the private sector and proactively promotes the deployment of PEVs in the United States.

4.1 POLICY, REGULATIONS, AND STATUTORY ISSUES

One barrier to PEV and charging station deployment is 23 USC 111, which limits commercial activities (such as PEV charging) in Safety Rest Areas along the Interstate System. MAP-21 expanded opportunities for federal funding of electric vehicle infrastructure by allowing PEV charging stations to be funded in fringe and corridor parking facilities—with Surface Transportation Program (STP) funds—and at other locations in air quality non-attainment areas—with Congestion Mitigation and Air Quality (CMAQ) funds.

Areas where FHWA and others may influence policy for the benefit of PEV deployment include, for each of the three pathways, the following.

Market Response

- Support the renewal of the Federal Tax Credit for PEVs.
- Support local state tax incentives for PEVs.
- Support the adoption of a single permit type for home charging stations at the state building code office.

Market Support

- Support one charging plug standard (CHAdeMO has the approval of the International Electrotechnical Commission).
- Support utilities in the development and implementation of time-of-use pricing, programmed off-peak charging, and the balancing of intermittent renewables with smart metering to support economically efficient means of electrifying the transportation sector.
- Support the development of Renewable Portfolio Standards in the states that sit in eGRID subregion grids that are the most carbon intense and have the densest PEV populations.

Market Acceleration

- Support increased performance in Corporate Average Fuel Economy standards. (While EPA and NHTSA found that the GHG and CAFE standards can be met primarily with improvements to conventional vehicles, further increased performance will promote PEV production).
- Support a national Low Carbon Fuel Standard that includes electric transportation energy. (These standards have been adopted in California and are being developed in other states. They require a reduction in the GHG intensity of transportation fuels by a specific percent. Increasing the use of electricity as a transportation fuel can help meet this requirement).
- Support increased performance in zero emission vehicles rules and the proliferation of these rules in other high population states. (This mandate is currently adopted by California and 11 other states, and requires the largest auto manufacturers to offer fuel cell vehicles, battery electric vehicles, plug-in hybrid electric vehicles, or advanced hybrids).
- Support third party right to sell electricity. (While this is outside the scope of FHWA's direct mission, many states define most sellers or resellers of electricity as "utilities," subjecting potential providers of charging points to substantial regulatory restrictions unless these are explicitly relaxed; In California, it has been ruled that charging station providers are not utilities, and therefore are not regulated by the state public utilities commission.)

4.2 EVSE IN DIFFERENT TRAVEL MARKETS

Currently, most PEV trip lengths are within the range of the battery, and most are commute trips to and from work. The implications for different travel markets and demand for installing publicly accessible charging stations depend upon:

- The type of PEVs—i.e., BEVs, PHEVs, or REEVs. (For PHEV and REEVs, charging is optional outside of commuting range. The owners may purchase gasoline or will charge when charging is convenient and less expensive than gasoline. This indicates that the BEV market should be the focus of policy development or action.)
- The geographic distribution of current PEV users and future market growth.
- Where the charging station is located—whether publicly accessible on or near the Interstate highway system, publicly accessible at local destinations away from the Interstate, or at home or work.

FHWA has some limited opportunities to develop charging stations in the ROW with federal funds. However, most of the deployment must happen off the ROW and in partnership with the private sector and local agencies, where commercialization is preferred or allowed.

Areas where FHWA and others may support the deployment of charging stations in different travel markets include, for each of the three pathways, the following:

Market Response – promote charging station opportunity sites

Public funds are available in certain locations and should be pursued by prioritizing those facilities that are nearest to the densest PEV populations and charging stations. These “hotspots” generally indicate the places where low elevation, temperate conditions, and incentives such as tax credits have created a supportive “ecosystem” for PEVs that warrants FHWA response. Such hotspots include:

- Transit stations and park-and-ride lots. MAP-21 Section 1401(d)(1) allows states to establish electric vehicle charging stations or natural gas vehicle refueling stations at “any parking facility funded or authorized by this Act or title 23.” to be funded in fringe and corridor parking facilities with Surface Transportation Program funds.
- Turnpike Rest Areas that are grandfathered exempt from commercialization bans (e.g., the Pennsylvania Turnpike).
- Non-toll Interstates with grandfathered exemptions (e.g., I-95 in Connecticut).
- Popular public-owned destinations near dense PEV and charging station cities such as parks and natural areas.

Market Support – develop charging station in key intercity corridors

This pathway focuses on the development of charging stations in intercity corridors between cities with dense PEV and charging station populations (e.g., Sacramento to San Francisco), mainly along the Interstate Highway System. These locations would require Public-Private-Partnerships (PPP) and must be adjacent to, but off of the ROW. Priority corridors indicated by the current density of vehicles and charging stations include:

- New York City to Washington, D.C.
- Atlanta, GA to Nashville, TN to St. Louis, MO.
- San Diego to Los Angeles, CA.
- Sacramento to San Francisco, CA.
- Portland, OR to Seattle, WA (building on existing installations).

Intercity corridors between dense PEV and charging station cities require about a 25–60-mile interval between stations. Multi-purpose commercial truck stops and gas stations are typically located at Interstate exits and are where most long-distance travelers currently stop for food, fuel, and supplies. With relatively good access (“easy-off” and “easy-on”), existing signage, and a robust electricity supply, these facilities offer some of the most promising potential locations for PPP charging stations. Other possible locations that may not be located on or along the ROW include: parking lots at venues where the public spends multiple hours at a time (shopping malls, restaurants, tourist attractions, theme parks, etc.); parking lots at venues where people stay overnight (hotels, motels, and bed-and-breakfasts); RV parks and other similar locations that are already equipped to provide charging to some extent; and state, county, or local rest areas, public parks, and waysides that are not on the Interstate highway system.

Market Acceleration – develop an expanded intercity charging station network

This pathway requires connecting the intercity corridors that are already connected between the densest PEV and charging station population cities (e.g., connecting the Sacramento–San Francisco corridor with the San Diego–Los Angeles corridor). This expanded network would be based on the Interstate Highway System, although it is likely that some Interstate links might be deferred, and possible that some non-Interstate links might be developed. By 2030, we can expect to see both an increasing number of PEVs and an increasing number of intercity trips conducted using those PEVs—especially if vehicle range is increased and the charge time is reduced to more acceptable levels during a typical trip. The market will also change, as early adopters make way for the “early majority.” Early majority drivers may be less adventurous than early adopters and more prone to range anxiety. The combination of these factors—growing proliferation of PEVs, improved suitability of PEVs for longer-range travel, and an increasing number of PEVs drivers likely to have range anxiety—collectively present a strong case for promoting connection between the intercity corridors charging station network by 2030.

4.3 HIGHWAY DESIGN STANDARDS AND INFRASTRUCTURE

PEVs do not present any particular challenges to typical roadway geometrics or design standards. A key premise of this analysis is that PEVs are, for the most part, replacements for conventional ICE vehicles. PEVs are not anticipated to create a different, additional market, or lead to an expansion of the total number of vehicles that would otherwise be using the nation's roads. PEV weights are currently roughly comparable to those of their ICE counterparts. Current design standards for infrastructure (including lane configurations and pavement types) already accommodate PEVs, and non-standard design features are not anticipated. Nevertheless, additional design standard accommodations can be made to promote PEV adoption, as noted below.

Areas in which FHWA and others may influence highway design standards and infrastructure include, for each of the three pathways, include the following:

Market Response

- Encourage state DOTs to consider PEVs' use of HOV lanes to encourage deployment.

Market Support

- Adopt standards for charger parking space dimensions to allow plug-in efficiency and ergonomics.

Market Acceleration

- Support research into the integration of charging technology and highway infrastructure (e.g., wireless charging).

4.4 SAFETY, EMERGENCY SERVICES AND INCIDENT RESPONSE

The safety concerns for PEVs are primarily incident response concerns and are rarely emergencies. The safety concerns include electrical and technological issues that are particular to the vehicle, not the transportation system, and require learning by emergency and incident responders, just as with LNG, CNG, and hydrogen. Battery fires in RVs are already understood by emergency responders and the same principles should be applied to PEVs.

The research team noted that "range anxiety" has been identified as a primary concern of many, but the actual problem of running out of charge appears to be a rare phenomenon. Although the data is thin, it is likely no more common than ICE out-of-fuel vehicle incidents (AAA states that each year, approximately 1.1% of their membership requires service for fueling problems).

Areas where FHWA and others may improve safety, emergency services, and incident response include, for each of the three pathways, include the following:

Market Response

- Promote the distribution of new national guidance that provides an online safety training course for first responders.
- Promote the distribution of information to second responders such as tow truck operators.

Market Support

- Coordinate and distribute safety information with NHTSA as needed; NHTSA chairs the Global Technical Regulations (GTR) international partnering effort to address occupant safety from high-voltage electric shock and safety protocols for electrical components.

Market Acceleration

- Continue to coordinate with NHTSA on safety and emergency response issues.

4.5 SIGNAGE, INFORMATION NETWORKS AND ONLINE MAPPING

Most of the need for signage relates to accurately identifying the location and type of charging. While a sign indicating PEV charging has received interim approval, the sign only indicates that PEV charging is available, and not what level of charging station is present.

Areas where FHWA and others may improve signage, information networks and online mapping include, for each of the three pathways, the following:

Market Response

- Provide better signage for motorists. Signage may be most useful if it differentiates between Level 2 and DC Fast (Level 3) and inductive charging. Current signage standards outlined in the Manual on Uniform Traffic Control Devices (MUTCD) do not make this distinction.
- Provide way-finding signage off the ROW, all the way to the actual locations of the charging station, which may not be as easily seen as traditional fueling stations.
- Develop parking space signage standards.

Market Support

- Promote the use of smartphone apps and other trip planning and charger wayfinding tools, such as <http://www.plugshare.com/> and DOE's Alternative Fuels Data Center's Alternative Fueling Station Locator, a new smartphone app developed by National Renewable Energy Laboratory to identify fueling stations that offer E85, natural gas, biodiesel, propane, electricity, or hydrogen (NREL, 2014).

- Develop “Next Charge in X miles” signage—signs must be kept current to be effective. In an emerging environment like PEV charging, stations may come and go at frequent intervals, and a mechanism for ensuring sign accuracy is critical.

Market Acceleration

- Continued promotion of smartphone apps and other trip planning and charger way finding.

4.6 REVENUE IMPACTS AND POTENTIAL COSTS

While there may exist a concern that PEVs have a significant negative impact on motor fuel tax receipts, research indicates that the revenues are eroding primarily due to CAFE standards. Because vehicle OEMs are partly complying with CAFE by producing PEVs, some effect is attributable to lessening revenues due to decreases in the volume of gasoline consumed. Consequently, FHWA may wish to consider revenue schemes for mitigating the impact of PEVs, even though policies targeted only to PEVs (such as a PEV tax or fee) are unlikely to solve the tax revenue problem. In addition to partially addressing possible revenue shortfalls, doing so would also give FHWA an opportunity to respond to possible concerns about the perceived lack of equity of some PEV transportation system users not “paying their fair share.”

Potential mechanisms for FHWA and others to increase revenue include, for each of the three pathways, the following:

Market Response

- No action suggested.

Market Support

- Consider state-level registration fees (for example, the legislature in the State of Washington levied a \$100 annual tax on PEVs, to be paid along with the vehicle’s annual registration fee, Virginia has since passed a similar levy, and other states have looked closely at the Washington model).
- Consider state efforts on VMT tax, such as Oregon’s pilot, for any vehicle that uses the ROW.

Market Acceleration

- Consider a federal-level PEV excise tax.
- Consider a Road User Fee to collect funding from the users of the system, regardless of vehicle technology or fuel type.

4.7 ADMINISTRATIVE ACTIVITY AND ADDITIONAL RESEARCH

The research team discovered that much of the knowledge of the market context is asymmetrical, and key players often harbor faulty assumptions about conditions in other specialists' domains. This imbalance indicates the general need for coordination across all of the major stakeholder groups. In these coordination efforts, FHWA should focus on "EV ecosystems" or "holistic solutions," combining marketing, infrastructure, education, incentives, and other means to create favorable conditions for PEV adoption. Additionally, several possible areas of additional future research became evident during this project, which are highlighted below.

Administrative activities and additional research that could be undertaken by FHWA and others for the benefit of PEV deployment include, for each of the three pathways, the following:

Market Response

- FHWA could switch a portion of its fleet to PEVs to provide important hands-on experience and potentially make administering charging infrastructure easier.
- Consider acting as the central coordinator of PEV information sharing *across federal agencies* and U.S.-based trade associations, such as the Electric Power Research Institute and major utilities (vertically integrated utilities may make good partners as they may have excess power availability and may be more motivated to act in advance of demand).
- Provide technical assistance to state-level programs and respond to their specific needs.
- Undertake additional research, in conjunction with EPRI, to map the actual locations of retail-dense interchanges that correlate to approximately 25–60-mile intervals on intercity corridors with PEV and charging station density; calculate the estimated intensity of use to determine the number of charging stations per station that would be required.
- Undertake additional research to track locations of charging stations to determine effectiveness of private-sector provision of a charging network in these corridors.
- Undertake additional research into future regional deployment variations using region-specific scenario analysis.

Market Support

- Distribute and promote the C2ES Plug-In Electric Vehicle Action Tool to state DOTs and local agencies.
- Undertake additional research, in conjunction with EPRI, to map the actual locations of retail-dense interchanges that correlate to approximately 25–60-mile intervals on a *broader* network that links all intercity corridors with PEV and charging station density;

calculate the estimated intensity of use to determine the number of charging stations per station that would be required.

- Initiate collaboration between FHWA and other federal, state, and local government agencies to develop public service advertisements to communicate the importance of PEVs on the overall transportation system.

Market Acceleration

- Expanded administrative and research activities described in the preceding pathways.

4.8 SUMMARY OF SUGGESTED PATHWAYS FOR FHWA, STATE DOTs, AND OTHER TRANSPORTATION AGENCIES

The pathways and accompanying actions discussed above are summarized in Table 41, below.

Table 41: Summary of suggested pathways for FHWA, State DOTs, and Other Transportation Agencies

Source	Market Response	Market Support	Market Acceleration
Policy, regulations, and statutory issues	<p>Support the renewal of the Federal Tax Credit for PEVs.</p> <p>Support local state tax incentives for PEVs.</p> <p>Support the adoption of a single permit type for home charging stations at the state building code office.</p>	<p>Support one plug standard.</p> <p>Support utilities in the development and implementation of time of use pricing, programmed off-peak charging and the balancing of intermittent renewables with smart metering.</p> <p>Support the development of state Renewable Portfolio Standards.</p>	<p>Support increased performance in CAFE standards.</p> <p>Support a national Low Carbon Fuel Standard.</p> <p>Support increased performance in, and expansion of, zero emission vehicle rules.</p> <p>Support third-party right to sell electricity.</p>
EVSE in different travel markets	<p>Promote charging stations at opportunity sites.</p>	<p>Develop charging station in key intercity corridors.</p>	<p>Develop an expanded intercity charging station network.</p>
Highway design standards and infrastructure	<p>Encourage PEV use of HOV lanes.</p>	<p>Adopt standards for charger parking space dimensions.</p>	<p>Support research into the integration of charging technology and highway infrastructure (e.g., wireless charging).</p>

Source	Market Response	Market Support	Market Acceleration
Safety, emergency services, and incident response	<p>Promote the distribution of new national guidance that provides an online safety training course for first responders.</p> <p>Promote the distribution of information to second responders such as tow truck operators.</p>	<p>Coordinate with NHTSA which chairs the Global Technical Regulations (GTR) international effort to address occupant safety from high-voltage electric shock and safety protocols for electrical components.</p>	<p>Continue to coordinate with NHTSA on safety and emergency response issues.</p>
Signage, information networks, and online mapping	<p>Provide better signage for motorists that differentiates between charging types.</p> <p>Provide way-finding signage off the ROW and all the way to the charging station.</p> <p>Parking space signage standardization.</p>	<p>Promote the use of smartphone apps (e.g., http://www.plugshare.com/ and Alternative Fueling Station Locator).</p> <p>“Next Charge in X Miles” signage.</p>	<p>Continued promotion of smartphone apps and other trip planning and charger way finding.</p>
Revenue impacts and potential costs	<p>No action suggested.</p>	<p>Consider state-level registration fees.</p> <p>Consider state efforts on VMT tax such as Oregon’s pilot for any vehicle.</p>	<p>Consider federal-level PEV excise tax.</p> <p>Consider a Road User Fee.</p>

Source	Market Response	Market Support	Market Acceleration
Administrative activity and additional research	<p>Switch a portion of FHWA’s fleet to PEVs.</p> <p>Lead the coordination of Federal agencies, EPRI, and vertically integrated utilities.</p> <p>Provide technical assistance to state-level programs and respond to their specific needs.</p> <p>Map the actual locations of retail-dense interchanges that correlate to approximately 25–60-mile intervals on intercity corridors.</p> <p>Track locations of charging stations to determine adequacy of corridor charging.</p> <p>Research future regional deployment variations</p>	<p>Distribute and promote the C2ES Plug-In Electric Vehicle Action Tool to state DOTs and local agencies.</p> <p>Map the actual locations of retail dense interchanges that correlate to approximately 25–60-mile intervals on a broader network that links all intercity corridors with PEV and charging station density.</p> <p>Collaborate with other government agencies on public service advertisements to communicate the importance of PEVs on the overall transportation system.</p>	Expanded administrative and research activities described in the preceding pathways.

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APPENDIX A: EVIDENCE USED TO DEFINE AVERAGE ANNUAL MILEAGE FOR THE DIFFERENT PEV CATEGORIES

U.S. DOE's Vehicle Technologies Program reports provide an evidence base for usage of a fleet of Nissan LEAFs (a BEV with 100-mile range), and a fleet of Chevrolet Volts (a REEV with 40-mile electric range)²⁹. Table A 1 and Table A 2, below, present data from the reports for the first and second quarters of 2013.

Table A 1: Nissan LEAF usage data for 2013 Quarters 1 and 2

Description	Quarter 1 2013	Quarter 2 2013
Vehicles in trial fleet	4,240	4,261
Numbers of trips	1,075,251	1,135,053
Distances driven (miles)	7,563,354	8,040,300
Average distance /year per vehicle (miles)	7,135	7,548
Average trip distance (miles)	7.00	7.10
Average distance /day (on days when used) (miles)	28.90	29.50
Days vehicle used	67.8%	70.3%

Table A 2: Chevrolet Volt usage data for 2013 Quarters 1 and 2

Description	Quarter 1 2013	Quarter 2 2013
Vehicles in trial fleet	1,766	1,895
Numbers of trips	526,156	676,414
Distances driven (miles)	4,369,753	5,753,009
Average trip distance (miles)	8.2	8.3
Average distance /day (on days when used) (miles)	39.4	41.0
Days vehicle used	67.8%	70.3%
Distance traveled in EV mode	3,166,649	4,289,168
Fraction of total mileage driven using electric power	72.50%	74.60%

Note: Assumptions used to define average annual mileage for the different PEV categories.

BEV 100-mile range – BEV 100 is comparable to a Nissan LEAF. From the table above, the average annual mileage of each Nissan LEAF was approximately 7,340 miles per year. This research rounds this to 7,300 miles per year, which is equivalent to a vehicle travelling an average of 20 miles per day, 365 days per year. The data in the table also indicate that on

²⁹ Quarterly reports on the US Department of Energy Vehicle Technologies Program are published by the Idaho National Laboratory, and are available from: <http://www.theevproject.com/documents.php>

average, vehicles were used for 69.1% of the days in the quarter. This is roughly equivalent to vehicles being used five days per week (which would be 71.4% of the time).

BEV 200-mile range – This research assumes that annual mileage for BEV 200 (vehicles with double the range of BEV 100) is 10,000 miles per year, 37% higher than the mileage of BEV 100. The basis of this figure is the assumption that people who buy higher specification vehicles will likely take advantage of the increased range.

BEV 300-mile range – This research assumes that annual mileage for BEV 300 (vehicles with triple the range of BEV 100) is 15,000 miles per year. This is equivalent to 41 miles per day, 365 days per year, or 75 miles per day for 200 days a year. Again, the basis of these figures is the assumption that people who buy higher specification vehicles will likely take advantage of the increased range.

PHEV/REEV 10-mile range – The Chevrolet Volt data indicate that PHEV/REEV 40-mile range vehicles travel 8,000 miles per year using electric power, and 30 miles/day on days when they are used. Based on the Chevrolet Volt (PHEV/REEV 40) data, this research assumes that PHEV/REEV 10-mile range vehicles travel, on average, 8.5 miles/day on electric charge, and use their ICE for any additional mileage. Assuming PHEV/REEV 10-mile range vehicles are driven for the same numbers of days per year as the PHEV/REEV 40-mile range vehicles (the usage figure for Chevrolet Volts), then over the course of year, a PHEV/REEV 10-mile range vehicle would travel 2,287 miles using electric charge. This figure is rounded up to 2,500 miles for this research.

PHEV/REEV 40-mile range – This vehicle category is comparable to the Chevrolet Volt. From the data above, the average annual mileage of each Chevrolet Volt is approximately 11,060 miles per year. However, this mileage includes miles traveled using its ICE. On average, it was found that 73.7% of the total miles traveled use electric power. This gives an average distance traveled using electric power of 8,150 miles per year, which is rounded to 8,000 miles for this research.

The data in the table also indicate the average distance traveled each day the vehicle is used is 40.2 miles. 73.7% of this distance (from above) yields an average of 30 miles traveled each day under electric power. This figure is used considering the electric range of PHEV/REEV 10-mile and PHEV/REEV 100-mile range vehicles.

PHEV/REEV 100-mile range – Assuming that the vehicle can be driven 88 miles before charging is needed, and that people who buy a PHEV 100-mile range vehicle (rather than a cheaper BEV 100-mile range vehicle) will want to travel further without charging, it is likely that yearly mileage would be greater than the 8,000 miles assumed for PHEV 40 and 7,300 miles for BEV 100. This research assumes annual mileage of 10,000 miles per year using electric charge for PHEV/REEV 100.

Current research includes little data **for light trucks**. However, it is useful to note that the average light truck mileage is about 13,000 miles per year—roughly the same as cars. Hence the data used in Table 30 is the same as for the passenger cars.

APPENDIX B: EVIDENCE USED TO DEFINE AVERAGE POWER CONSUMPTION PER MILE DRIVEN FOR THE DIFFERENT PEV CATEGORIES

Evidence to support the average power consumption per-mile values provided in Table 31 is given below.

Passenger PEVs generally

Foundational research suggested **0.25–0.40 kWh/mile**.

Nissan LEAF BEV

Official figures for this vehicle are 24 kWh capacity and 106-mile range—i.e., **0.226 kWh/mile**. The quarterly reports published by the Idaho National Laboratory (INL) on the U.S. DOE Vehicles Technology Program do not provide sufficient data for actual consumption to be calculated for the fleet of Nissan LEAFs in the program. However, data for a range of vehicles from the DOE ARRA project were summarized in a presentation given by J. Francfort (Idaho National Laboratory) to SAE in January of 2012.³⁰ The data indicated that LEAFs traveled on average 31 miles per day, and 30 miles per charge, and that there was one charge per vehicle per day, 4.3 trips per charge, and 7.5 kWh per charge. These figures result in calculated average per-mile power consumption of **0.25 kWh/mile**.

Chevrolet Volt

Again using the DOE ARRA project data summarized in the presentation by J. Francfort of INL to SAE in January of 2012, Chevrolet Volts (a REEV 40-mile range vehicle) were found to use an average **0.37 kWh/mile** under electric drive only. The quarterly reports published by INL on the U.S. DOE Vehicle Technology Program do not provide sufficient data to calculate the average power consumption for the fuel economy under electric drive, because these reports do not include quantity of gasoline used by the REEV.

Light truck PEVs generally

The average electric charge required to drive a mile in a light truck is much more difficult to assess because there are fewer data available. However, because these vehicles are only a small component of all the PEVs, the overall analysis is not too sensitive to this figure.

³⁰ Presentation available from: <http://avt.inl.gov/pdf/phev/G100SAEGovtIndustryJan12.pdf>

Light truck PHEVs: Data are taken from the analysis of Chrysler RAM and Ford Escape Advance Research Vehicles outlined in the presentation by J Francfort of INL to the SAE in January 2012, and from the VIA Motors VTrux data provided by Plug In America³¹.

- Chrysler RAM:
 - In charge sustaining mode (i.e. powered by ICE only) it had a 13 mpg gasoline fuel economy (i.e. used 0.07692 gallons per mile).
 - In charge depleting mode (i.e. powered by ICE and battery) it used both 20 mpg (0.050 gallons per mile) and 282 Wh/mile.
 - Together, these indicate 0.02692 gal/mile is equivalent to 282 Wh/mile.
 - Hence for this vehicle 10.5 kWh is equivalent to 1 gallon gasoline.
 - If it were powered by electric power only, then overall the vehicle would use 805 Wh/mile.
- Ford Escape:
 - In charge-sustaining mode (i.e. powered by ICE only) it had a 32 mpg gasoline fuel economy (0.0315 gallons per mile).
 - In charge depleting mode (i.e., powered by ICE and battery) it used both 53 mpg (0.01887 gallons per mile) and 165 Wh/mile.
 - Together, these indicate 0.01238 gal/mile is equivalent to 165 Wh/mile.
 - Hence for this vehicle, 13.33 kWh is equivalent to 1 gallon gasoline.
 - If it were powered by electric power only, then overall the vehicle would use 420 Wh/mile.
- VIA Motors VTrux sales brochure states a range of 40 miles on 27 kWh, or 675 Wh/mile.

To summarize, for the three light truck PHEVs discussed above, the average power consumption per mile driven under electric power (the factor important to establish the quantity of gasoline displaced) are:

- Chrysler RAM 805 Wh/mile.
- Ford Escape 420 Wh/mile.
- VIA Motors VTrux 675 Wh/mile.

The data also enables the electric power to gasoline equivalence to be calculated for two vehicles.

- Chrysler RAM 10.5 kWh is equivalent to 1 gallon of gasoline.
- Ford Escape 13.33 kWh is equivalent to 1 gallon of gasoline.

Light truck BEVs: No data available, so this research uses the hybrid figure of **0.80 kWh/mile**.

³¹ <http://www.pluginamerica.org/vehicles/via-motors-vtrux>

APPENDIX C: EVIDENCE USED TO DEFINE THE AVERAGE NUMBER OF KWH REQUIRED TO DISPLACE A GALLON OF GASOLINE

Table A 3: Evidence from U.S. Department of Energy and U.S. Environmental Protection Agency's fuel economy website³²

Vehicle	Model year	Electric consumption	Gasoline fuel economy	Number of kWh that are equivalent to 1 gallon
Ford Fusion Energi & Ford C-Max Energi	2013	0.34 kWh per mile	43 mpg	14.6
Chevrolet Volt	2013	0.35 kWh per mile	37 mpg	12.9
Chevrolet Volt	2012	0.36 kWh per mile	37 mpg	13.3
Fisker Karma	2012	0.62 kWh per mile	20 mpg	12.4
Toyota Prius	2013	0.29 kWh per mile & 0.2 gal	50 mpg	13.1
Average for five models	-	-	-	13.3 +/- 0.8

Evidence from U.S. Department of Energy's research programs

Data for a range of vehicles from the DOE ARRA project were summarized in a presentation given by J Francfort (Idaho National Laboratory) to SAE in January of 2012.³³ Data were provided for:

- Chevrolet Volt (REEV passenger car).
- Ford Escape Advanced Research Vehicle (PHEV Compact SUV).
- Chrysler RAM (PHEV Pickup).

Chevrolet Volt: When powered by its electric motor, this vehicle requires on average 370 Wh to travel one mile, and travels 37.2 miles per gallon on gasoline only using its ICE. To travel the same distance (37.2 miles) at 370 Wh per mile would use 13.76 kWh battery charge. Hence 1 gallon of gasoline is equivalent to **13.76 kWh** electricity.

³² Summarized at http://en.wikipedia.org/wiki/Miles_per_gallon_gasoline_equivalent

³³ Presentation available from: <http://avt.inl.gov/pdf/phev/G100SAEGovtIndustryJan12.pdf>

Ford Escape Advanced Research Vehicle: An analysis of this vehicle's electric and gasoline consumption was given in Appendix B, concluding that for this vehicle, 1 gallon of gasoline is equivalent to **13.33 kWh** electricity.

Chrysler RAM: An analysis of this vehicle's electric and gasoline consumption was given in Appendix B, concluding that for this vehicle, 1 gallon of gasoline is equivalent to **10.5 kWh** electricity.

Evidence from U.S. Department of Energy's Vehicle Technologies Program

Beyond the ARRA program discussed above, the U.S. Department of Energy Vehicle Technologies Program reports provide an evidence base from a fleet of Chevrolet Volts. The key data given in the 2013 quarter 1 and 2 reports are tabulated below.

Table A 4: FY 2013 Q1 and Q2 evidence base from a fleet of Chevrolet Volts

Parameter	Quarter 1	Quarter 2
Average number of vehicles in trial	1,766	1,895
Total number of miles in quarter	4,369,753	5,753,009
Distance traveled in EV mode	3,166,649	4,289,168
Fuel economy in EV mode Wh/mile	350	310
Distance traveled in extended mode	1,203,104	1,463,842
Fuel economy in extended mode miles/gallon	34.8	36.1

The distance-weighted average electric fuel economy from the data above is 327.3 Wh/mile. The fuel economy varies, and is lower (consuming more electricity per mile traveled) in the first quarter than in the second quarter. This difference may be due to greater use of vehicle heaters in the winter months. Nevertheless, the average figure of 327.3 Wh/mile (an average from approximately 7.5 million miles driven) is consistent with the earlier findings.

Regarding the fuel economy in extended mode (where the vehicle uses its ICE only) the mileage weighted average is 35.5 mpg.

On this basis, for this data the equivalence is 11.6 kWh equal to 1 gallon of gasoline. Again, this figure appears lower than the official test figures, possibly due to the ICE being used to replenish the battery in addition to powering the vehicles' motion, and/or the official data being collected with no auxiliary equipment drawing power (e.g., the heater turned off). A vehicle with an ICE requires little additional power to provide heat, because the engine produces waste heat, and turning the heater on tends to redirect some of the waste heat into the cabin. In contrast, for a PEV, the provision of cabin heat directly depletes the battery.

Projections into the future

The three preceding sections have presented evidence regarding the number of kWh required to travel an “average” mile for PEVs, and the amount of gasoline required to travel an “average” mile for analogous ICE vehicles (often expressed as the number of miles traveled per gallon, or mpg). The main conclusion is that at present, approximately **13 kWh** displaces 1 gallon of gasoline. Because the average power consumption per mile traveled is predicted to vary with time for different PEV categories, future projections must also be made.

Efficiency of PEVs: Table A 5 below presents average power consumption per mile traveled over time for various PEV categories. These averages are based on the assumed improvements in efficiency in the table below.

Table A 5: Average power consumption per mile traveled over time for different PEV categories

Year range	2012– 2020	2020–2030	2030–2040	2040–2050	2050
Efficiency improvement per year	0.3%	0.8%	0.9%	0.9%	
Year	2012	2020	2030	2040	2050
Relative energy efficiency	1.000	0.976	0.901	0.823	0.752

This is a relatively smooth function from 2012 to 2050. The blue line on the figure below displays the trend graphically.

Efficiency of the ICE vehicles displaced: This research uses the DOE AEO 2013 projections of the gasoline used in U.S. passenger cars out to 2040, along with VMT projections. From these data, the average fuel economy for the passenger car fleet can be calculated. Because passenger cars are the largest fraction of PEVs, this focus is appropriate. The raw data and calculated “average” mpg for passenger cars are given below. Data for 2050 are also applied to 2040 because CAFÉ and GHG regulations will have worked through the fleet.

Table A 6: Raw data and calculated “average” mpg for passenger cars

Description	2012	2020	2030	2040	2050
Cars' energy consumption (trillions btu)	375.6	429.0	370.4	425.5	-
Cars' energy consumption (billions gallons)	3.290	3.758	3.245	3.727	-
Cars' VMT (billions miles)	84.32	111.87	125.63	143.95	-
Average mpg	25.6	29.8	38.7	38.6	38.6
Relative mpg	1.000	1.162	1.511	1.507	1.507
Relative energy efficiency	1.000	0.861	0.662	0.664	0.664

The relative energy efficiency of ICEs is far from smooth. From 2012 to 2025, it increases quite steeply, due to the projected phased improvement in energy efficiency of ICE vehicles caused by the implementation of Phase I of CAFE and GHG standards (the National Program), affecting model years 2012–2016, and then Phase II of CAFE and GHG standards, affecting model years 2017–2025. After 2025, it is presumed that the average relative energy efficiency of new ICEs remains constant. However, there is a longer term impact as the more energy-efficient current vehicles replace retiring vehicles over the next 15 years. This replacement leads to a slower rate of improvement relative to pre-2025. There are no data from AEO 2013 for ICE efficiency after 2040. By 2040, it is assumed that the whole light vehicle fleet has the energy efficiency required in 2025. The red line on the figure below displays the trend graphically.

Combined effect: The individual effects of changes in efficiency of PEVs and ICEs discussed above combine to give a projection regarding how the 2012 equivalence of 13 kWh to 1.0 gallon of gasoline will vary in the future. As the efficiency of the PEV increases, fewer kWh are required to replace each gallon of gasoline, and the equivalence becomes smaller than 13. Conversely, if the efficiency of the ICE increases, then less gasoline is required to travel each mile, while the PEV requires the same number of kWh, and the equivalence will become larger than 13. This time-dependent relative efficiency of PEVs and ICEs is shown in Figure A 1 below, with both efficiencies set at 1.0 for 2012. The thick green line shows the combined effect.

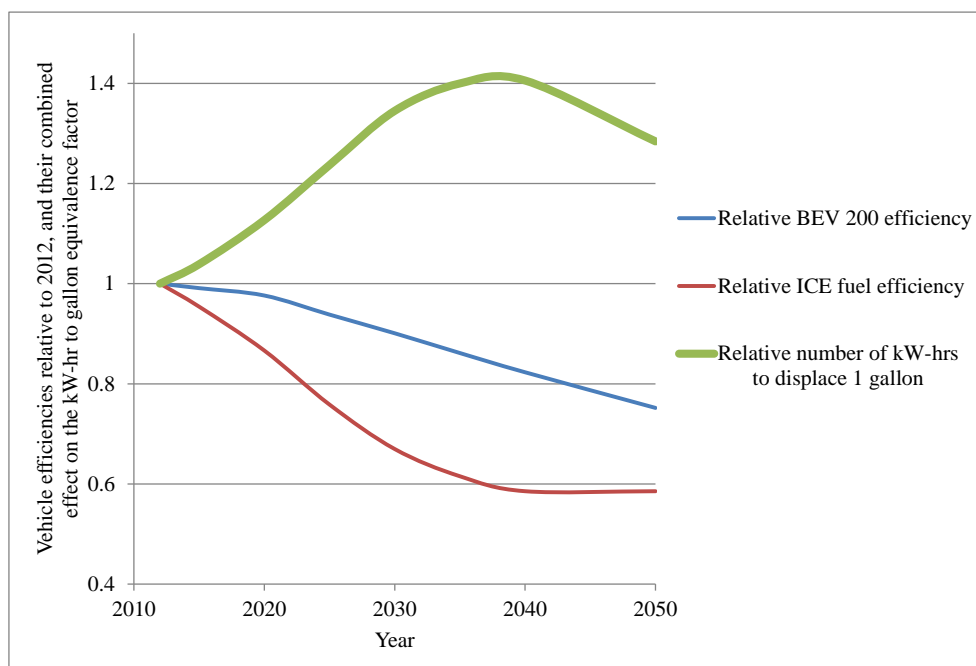


Figure A 1: Time-dependent relative efficiency of PEVs and ICEs

Table A 7: Ratio of electricity to gasoline consumption

Year	2012	2020	2030	2040	2050
Energy equivalence kWh per gallon of gasoline	13.0	14.6	17.5	18.3	16.7

The above is far from a smooth function. From 2012 to 2030, it increases, due to the rapid projected improvement in energy efficiency of ICE vehicles dominating the more modest improvement in energy efficiency of PEVs. Then it falls following minor projected ICE vehicle energy efficiency improvements and continuing modest improvement in energy efficiency of PEVs.

APPENDIX D: EVIDENCE USED TO SUPPORT THE ASSUMPTIONS MADE ABOUT CHARGING CHARACTERISTICS AT PUBLICLY ACCESSIBLE CHARGING POINTS

Average Charging Characteristics

The U.S. Department of Energy Vehicle Technologies Program reports provide an evidence base for the characteristics of charging events at residential, private AC Level 2 charge points and at publicly accessible charging stations³⁴. The table below presents data from the 2013 1st Quarterly Report.

Table A 8: Average charging characteristics at residential, private and publicly accessible charging points from the 2013 First Quarterly Report

Characteristic	Residential AC Level 2	Private AC Level 2	Publicly accessible AC Level 2	Publicly accessible DC Fast chargers
No. of units	6,031	189	2,288	72
No. of events	440,480	8,160	39,046	13,507
Charge kWh	3,924,030	91,640	322,530	102,000
Charge per event	8.91 kWh	11.23 kWh	8.26 kWh	7.55 kWh
Events per unit	73	43	17	188
Percent of time with a vehicle connected to unit	44%	19%	4%	3%
Percent of time with a vehicle drawing power	9%	9%	2%	3%

³⁴ See “EV charging infrastructure reports” of the quarterly reports on the US Department of Energy Vehicle Technologies Program, published by the Idaho National Laboratory, available from: <http://www.theevproject.com/documents.php>

Table A 9: Average charging characteristics at residential, private, and publicly accessible charging points from the 2013 Second Quarterly Report

Characteristic	Residential AC Level 2	Private AC Level 2	Publicly accessible AC Level 2	Publicly accessible DC Fast chargers
No of units	6,141	251	2,675	87
No of events	490,327	11,948	50,729	26,911
Charge kWh	3,808,410	143,890	437,690	222,520
Charge per event	7.77 kWh	12.04 kWh	8.63 kWh	8.27 kWh
Events per unit	80	48	19	309
Percent of time with a vehicle connected to unit	43%	20%	4%	5%
Percent of time with a vehicle drawing power	8%	9%	2%	5%

The average charge transferred per charging event: Currently for publicly accessible AC Level 2 chargers the average is 8.44 kWh. This research uses 10 kWh (since it is assumed a modest increase will occur as users of PEVs increase their usage of publicly accessible charging points). Currently for publicly accessible DC Fast chargers the average is 7.91 kWh. However, these are charging points on standard ROWs, not on the Interstate where vehicles typically travel longer distances. The figure used in Table 36 for Interstate highway charging is 20 kWh per charge, which is based on the professional judgment of the research team.

The rate and duration of charge transfer: These are not independent variables, because the rate of charging is within the specification of Level 2 and DC Fast charging protocols. Once the average charge transferred per charging event has also been fixed, the duration of the charge transfer is simple to calculate.

The average length of time each vehicle is connected to the charging point: The data tabulated above gives both the percent of time a vehicle is connected to each charging unit, and the percent of time a vehicle draws power. The ratio of these percentages indicates the duration of time that vehicles are attached to the charging points past the time of charging. These ratios are:

Table A 10: Ratio of the duration of charge

Characteristic	From 2013 1st Quarterly Report	From 2013 2nd Quarterly Report
Publicly accessible AC Level 2	2.0	2.0
Publicly accessible DC Fast chargers	1.0	1.0

The average number of charging events per year, per charging point: Currently, for publicly accessible AC Level 2 chargers, the average number of events is 18.1 per quarter, or 72.4 per year. This research assumes 75 per year for 2012. Currently, for publicly accessible DC Fast chargers, the average number of events is 254.2 per quarter, or 1,016.8 per year. This research assumes 1,000 per year for 2012.

The INL quarterly reports also show quite different patterns for residential, private commercial, and publicly accessible charge points. Residential charging points can have a high percentage of time with a vehicle connected (average approximately 44%) but a low percentage of time when the vehicle is actually drawing power (average approximately 9%). Publicly accessible charging points tend to have less time with a vehicle connected (relative to residential charging points), but the duration of vehicles drawing power is a higher proportion of time.

APPENDIX E: SUMMARY OF RESEARCH BY NHTSA ON EVS

Information was obtained from an interview with the Chief of Structures and Restraints Research Division in October of 2013.

One current NHTSA standard relates to PEVs. Federal Motor Vehicle Safety Standards and Regulations (FMVSS) No. 305 “specifies performance requirements for limitation of electrolyte spillage, retention of propulsion batteries, and electrical isolation of the chassis from the high-voltage system during the crash event. This standard applies to vehicles that use electricity as propulsion power.”³⁵

NHTSA is involved in four research initiatives related to PEVs:

- **Crash impact testing:** NHTSA is partnering with SAE International and Ford to independently measure battery safety, including tests for water immersion, capacity, shock, vibration, and propagation. Research and findings will be completed and published by Spring of 2014.
- **Standardized emergency responder standard operating procedures:** NHTSA is partnering with Argonne National Laboratory to determine the possibility of standardizing an approach by first responders to emergency incidents involving electric vehicles. Research and findings will be completed and published within the next two years.
- **Performance standards:** NHTSA is partnering with SAE International and battery manufacturers/suppliers to test for standards for shock vibration, “no smoke-no fire,” “thermal runaway” indicators, and degradation. These tests represent longer-term research but are focused on common measurement thresholds typically measuring voltage, temperature, modules, and isolation.
- **Global Technical Regulations (GTR):** NHTSA serves as the chair of this international effort partnering with China and Japan on global technical regulations for electric vehicles. GTR will address occupant safety from high-voltage electric shock during and after crash events, as well as develop safety protocols for electrical components used for charging stations or residence. GTR has an aggressive timeline, although testing is necessary prior to agreement and finalization of the regulations.

³⁵ U.S. Department Of Transportation, National Highway Traffic Safety Administration, “Laboratory Test Procedure for FMVSS 305, Electric Powered Vehicles: Electrolyte Spillage And Electrical Shock Protection.” September 2008. <http://www.nhtsa.gov/Vehicle+Safety/Test+Procedures>

Apart from these research areas, NHSTA works regularly with DOE on battery modeling as well as longer-term efforts such as wireless charging.

APPENDIX F: CASE STUDIES OF EV DEPLOYMENT

1. CASE STUDY: OREGON'S INTERSTATE-5 CORRIDOR (INCLUDING PORTLAND, SALEM, CORVALLIS, EUGENE)

1.1 Overview

The Interstate-5 (I-5) corridor stretches North-to-South along the western edge of Oregon and approximately 50 miles from the Pacific coast. The interstate connects many of Oregon's largest cities, including Portland, Salem, Corvallis, and Eugene.

Of the many electric vehicle (EV) deployment initiatives in place in Oregon, several are directed at promoting the construction of electric vehicle supply equipment (EVSE) infrastructure along the I-5 corridor. In fact, I-5 forms part of the West Coast Electric Highway, a key component to the broader vision for the West Coast Green Highway that will eventually provide infrastructure stretching from Canada to Mexico for alternatively-powered vehicles. EV development along the I-5 corridor is currently most relevant to inhabitants of dense urban and suburban centers, however eventual expansion of EV infrastructure is anticipated to also reach the broader population across Oregon's small rural towns, ranches, and farms.

1.2 Focus of Planning Efforts

Oregon's state government has promoted the development of EV charging infrastructure in the state, and coordinated much of the subsequent deployment activity. In 2010, former Governor Ted Kulongoski appointed a Transportation Electrification Executive Council (TEEC), which is composed of representatives from the EV industry, utilities, higher education, and local and state governments.

In collaboration with the Office of the Governor and Business Oregon—and with support from the U.S. Department of Energy's (DOE) Clean Cities program—TEEC led a year-long planning process to develop *Energizing Oregon*, an EV-readiness strategic plan for the state. The goals of Energizing Oregon are to:

1. Integrate all existing plug-in electric vehicle (PEV)-readiness efforts.
2. Develop a statewide PEV market.
3. Build momentum toward Oregon's stated goal of exceeding its share of President Obama's PEV deployment goal of 1 million PEVs on the road by 2015.

To achieve these goals, TEEC established four working groups to identify key leverage points for promoting the growth of the EV market in Oregon. The leverage points and associated strategies are as follows.

1.2.1 Deployment Priorities

- Develop a workplace charging program to incentivize companies to install charging stations for employee use.
- Establish financing mechanisms to facilitate incorporation of EVs into vehicle fleets.
- Integrate EVs into existing sustainable tourism initiatives by promoting travel itineraries that take advantage of the expanding EV charging network.
- Develop clear and consistent signage for charging station, such as that made possible by FHWA's update to the *Manual on Uniform Traffic Control Devices* in 2011, which gave interim approval to a charging station general service symbol sign on state highways.

1.2.2 Policy Priorities

- Pilot residential building-code modifications to ensure compatibility with charging station.
- Provide financial incentives for EV purchasing.
- Leverage other relevant policy initiatives, such as Oregon's Zero-Emission Vehicle rules, the Road Usage Charge Program, and municipal planning efforts.

1.2.3 Outreach and Communications Priorities

- Develop a brand identity for EVs in Oregon.
- Create “experiential marketing” opportunities for members of the public to see and test-drive EVs.
- Maintain critical training programs to inform auto dealers and electricians about EV and charging station deployment.

1.2.4 Utility Priorities

EV planning initiatives in Oregon focus on engaging utilities and alleviating their uncertainties around EV and charging station deployment. Specific priorities include:

- Develop robust information collection and sharing systems to inform utilities about demographics, charging station usage patterns, and approaches taken by other utilities.
- Develop a systematic notification mechanism to inform utilities about EV purchases and installation of new commercial or residential EV charging units.

- Seek public investment in rural or remote charging stations, in cases where current grid infrastructure is insufficient.

The Oregon Public Utilities Commission (OPUC) has ruled that individual providers of EV charging services are not subject to OPUC regulation under Oregon statute. This exemption has been a boon to the growth of EV charging infrastructure.

1.3 Infrastructure Development

The Oregon Department of Transportation (ODOT) has supported EV charging infrastructure deployment guidelines since 2010³⁶. In addition, ODOT has administered and assisted several large projects to develop EV infrastructure in the state:

- Oregon was one of six states chosen to participate in U.S. DOE's *EV Project*, aimed at supporting nationwide adoption of EV technology. Since 2011, the project, administered by company ECOtality, has been installing residential, workplace, and municipal EV Level 2 charging equipment in the major cities along I-5, with more than 450 stations in the resulting Blink charging network as of September 2014³⁷.
- With funding from the American Recovery and Reinvestment Act of 2009 (ARRA), ODOT hired AeroVironment to install DC Fast charging stations at 10 key intersections along the I-5 corridor in southern Oregon, creating over 200 "PEV-ready" miles that form part of the West Coast Electric Highway network.
- Through U.S. Department of Transportation's (DOT) Transportation Investment Generating Economic Recovery (TIGER) discretionary grant program, ODOT has expanded EV infrastructure along other key corridors in Northwest Oregon. The expansion consists of 33 additional DC Fast charging stations through the summer of 2014, with further sites planned³⁸.

³⁶ *Electric Vehicle Charging Infrastructure Deployment Guidelines for the Oregon I-5 Metro Areas of Portland, Salem, Corvallis, and Eugene*, 2010. Electric Transportation Engineering Corporation (eTEC). <http://www.oregon.gov/ODOT/HWY/OIPP/docs/evdeployguidelines3-1.pdf>

³⁷ "Blink – BlinkMap." Car Charging Group, Inc. <http://prod.blinknetwork.com/blinkMap.html>

³⁸ "Electric Vehicles and Infrastructure Program." Oregon Department of Transportation. http://www.oregon.gov/ODOT/HWY/OIPP/Pages/inn_ev-charging.aspx

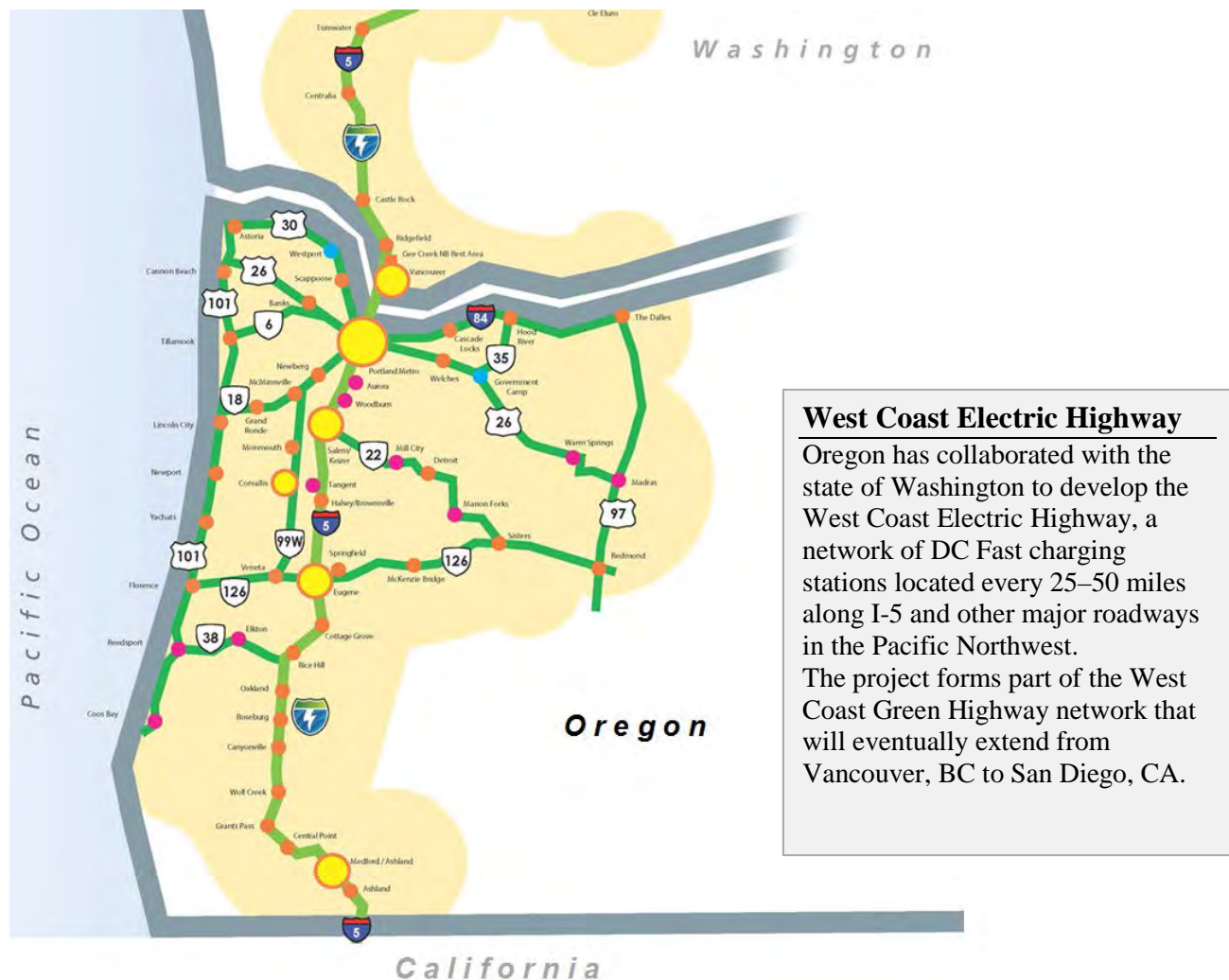


Figure A 2: Map of the West Coast Electric Highway³⁹

On a smaller scale, Level 1 and Level 2 charging units are being installed at residential and commercial sites in Oregon. According to U.S. DOE's Alternative Fuels Data Center, which maintains a non-exhaustive list of EV charging equipment around the country, there are 373 publicly-available EV charging stations installed in Oregon as of September 2014.

Further state-led development includes Oregon Senate Bill 536, passed in June 2013, which permits state agencies to install EV charging equipment on state-owned premises⁴⁰.

³⁹ Oregon Department of Transportation. http://www.oregon.gov/ODOT/HWY/OIPP/docs/EV_WCEHMap.jpg

⁴⁰ State of Oregon Senate Bill 536: Relating to State Provision of Energy for Motor Vehicles, 2013. <http://gov.oregonlive.com/bill/2013/SB536/>

1.4 Electric Vehicle Distribution within Oregon

Oregon is home to more than 3 million licensed drivers and 3.2 million registered vehicles. Mass-market electric vehicles have been available in Oregon since November of 2010. Among the 1,610 PEVs registered in Oregon as of September 2012, the vast majority were registered in counties along the I-5 corridor, as shown in Figure A 3.

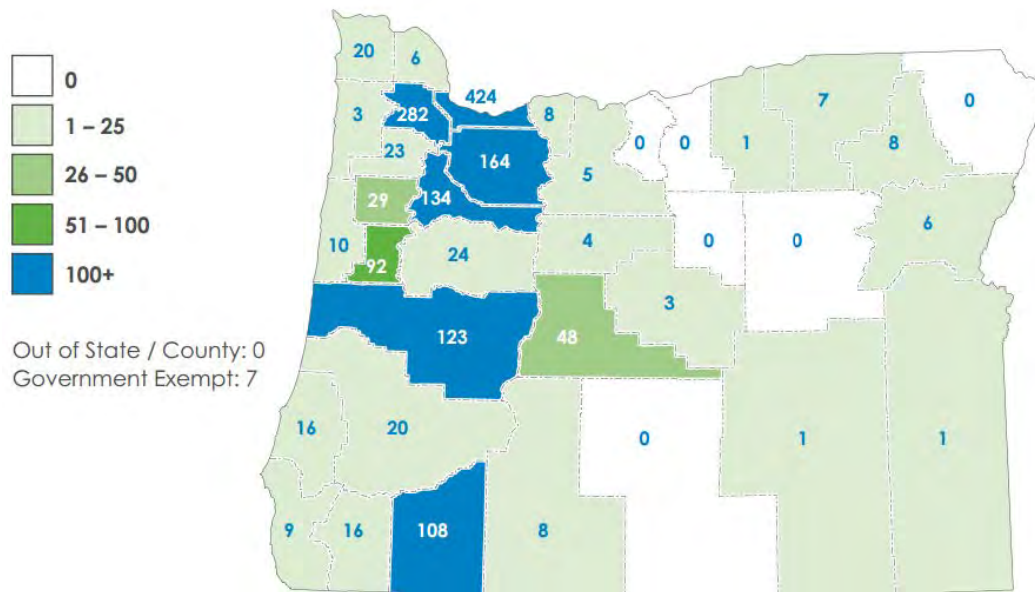


Figure A 3: EV Registrations in Oregon by County⁴¹

1.5 Training of Key Stakeholders

Various actors in the state-coordinated EV efforts have developed and supported the training of key stakeholder groups. Contributions to this training include:

- The NECA-IBEW Local 48 electrical workers' union developed and offered two levels of training related to DC Fast chargers: (1) an introductory course for a broad audience, and (2) an in-depth training for industry professionals active in charging station installation.
- Energizing Oregon and the Oregon Auto Dealers Association conducted direct outreach to auto dealers to promote EV, both through a large presence at a recent the Portland International Auto Show, and in a series of training sessions for auto dealers across the state. (*Energizing Oregon*, p.17).

⁴¹ *Energizing Oregon*, Business Oregon. <http://www.oregon4biz.com/assets/docs/EVrpt2013.pdf>

- The Rogue Valley Clean Cities Coalition—the southern-Oregon regional group of the U.S. DOE’s Clean Cities program—developed an EV training session for emergency first responders in the region.
- After conducting initial outreach to and survey of Oregon electric utilities, the TEEC Utilities working group conducted a four-part webinar series for Oregon utilities on PEVs, usage patterns, electrical system impacts, and rate-related issues.

1.6 Emergency-Response Services

State-level planning has not included significant changes to emergency response protocols. However, AAA launched a pilot program in Portland in 2011 offering emergency roadside-charging services in the form of a specialized truck with an on-board electric generator, shown in Figure A 4, below. AAA also offers this service in San Francisco, Los Angeles, Seattle, Knoxville, TN, and Tampa Bay, FL⁴². The truck supports both DC Fast charging and Level 2 AC charging, and provides up to 15 minutes of charge time to a member with a discharged electric vehicle⁴³.



Figure A 4: AAA Roadside Assistance Vehicle for Electric Cars⁶

1.7 Road Usage Charge Program

In 2001, the Oregon Legislatures created a Road User Fee Task Force to investigate options the state might have for creating a sustainable way to generate funds to support the transportation system. Years later in 2013, after investigating options and conducting two pilot projects in 2007

⁴² “AAA unveils emergency charging truck for electric cars,” 2013. Dvice.com. <http://www.dvice.com/2013-3-21/aaa-unveils-emergency-charging-truck-electric-cars>

⁴³ “AAA charging up roadside assistance for electric-vehicle drivers (poll),” 2012. *The Oregonian*. http://blog.oregonlive.com/commuting/2012/07/aaa_charging_up_roadside_assis.html

and 2012, the Oregon Legislatures passed Senate Bill 810 (SB810), the first legislation in the United States to establish a road usage charge system for transportation funding. SB810 authorizes ODOT to assess a charge of 1.5 cents per mile, beginning in July 2015, for up to 5,000 volunteer cars and light commercial vehicles, whose owners will receive a gas tax refund in exchange for participating⁴⁴. The bill aligns with the TEEC Policy working group's recommendation that a road user fee program include, but not specifically single out, EVs.

Although participation is voluntary, the law—and similar previously proposed state bills that didn't pass committee—indicate Oregon policymakers' awareness of the long-term need to find alternative sources of revenue to compensate for the decline in gasoline tax revenues, which supply approximately 60 percent of Oregon's road improvement budget. As the prevalence of alternative-fuel vehicles continues to increase, gasoline tax revenue will continue to decrease⁴⁵.

⁴⁴ "Road Usage Charge Overview," Oregon Department of Transportation.
http://www.oregon.gov/ODOT/HWY/RUFPP/Pages/ruc_overview.aspx

⁴⁵ "Oregon proposes 1.5-cent-per-mile mileage tax for EVs, would also target 55+ mpg cars," 2013. AutoblogGreen.
<http://green.autoblog.com/2013/03/03/oregon-proposes-1-5-cent-per-mile-mileage-tax-for-evs-would-als/>

2. CASE STUDY: TEXAS GREATER HOUSTON AREA

2.1 Overview

The City of Houston is the fourth largest city in the United States and the largest in Texas, with a population of 2.1 million. The seven-county Greater Houston region consists of approximately 1,300 square miles and 6.2 million inhabitants.

The City of Houston has noted that two key factors contributing to the potential for strong electric vehicle (EV) growth in the greater Houston area are (1) the size of the general vehicle market, and (2) the severity of local air quality issues, which could be mitigated by the adoption of zero-emission vehicles.



Figure A 5: The Greater Houston region covered by the City's EV readiness plans.

Houston is one of sixteen cities to participate in U.S. DOE's *EV Project*, which promotes widespread adoption of EV technology across the country. Major EV infrastructure planning in the Greater Houston area has been led by the City of Houston with support from the William J. Clinton Foundation. These efforts have focused primarily on the development of the following:

1. Recommended Electric Vehicle Charging Infrastructure Deployment Guidelines
<http://www.greenhoustontx.gov/ev/pdf/evdeploymentguidelines.pdf>
2. Electric Vehicle Charging Long Range Plan (the Long Range Plan)
<http://www.greenhoustontx.gov/ev/pdf/longrangeevplan.pdf>
3. Electric Vehicle Charging Micro-Climate™ Plan (the Micro-Climate Plan)

<http://www.greenhoustontx.gov/ev/pdf/micorclimateplan.pdf>

2.2 Focus of Planning Efforts

Houston's broad planning initiative is grounded in thorough analysis and a focus on demand. The Micro-Climate Plan draws on extensive analysis of demographic information, employment data, commuting and other travel patterns, land use projections, and input from a variety of stakeholders to determine optimal locations for EV service equipment across the region. The plan goes so far as to estimate appropriate densities of EV charging equipment in all locations within the designated EV Project area, and includes maps showing the calculated optimal locations within a ¼-mile radius of the project area.



Figure A 6: Map of calculated optimal density for public Level 2 EV charging units, as calculated in the Micro-Climate Plan.

The plans focus on five types of EV charging equipment placement:

1. Home-based, single-family residential.
2. Multi-family residential.
3. Workplace charging.
4. Publicly available charging (including at key regional attractions).
5. DC Fast charging stations.

The City's EV infrastructure planning efforts have focused on developing an EV charging network that provides sufficient public charging stations to meet the anticipated level of demand. This market-focused approach is based on the city's recognition that a readily available infrastructure is necessary for a smooth transition from gasoline to electric vehicles and for consumer acceptance of electric transportation in the region.

The City's focus on demand is also evident in its approach to identifying optimal locations for new charging stations. Potential sites were designated based on proximity to (1) neighborhoods with likely EV ownership; (2) likely workplaces and commuting routes for EV drivers; and (3) key regional attractions where EV owners are likely to spend 45 minutes to 3 hours of time (making them suitable for Level 2 charging).

The City calculated that in order for every point in the Houston urbanized area to be within one mile of a charging station, fewer than 400 charging station locations would be required. For the sake of comparison, there are an estimated existing 1,000 conventional fueling locations in the Houston urbanized area of 1,300 square miles.

The planning focus is on Level 2 charging station for most publicly available charging, at locations where an EV could be charged for 45 minutes to 3 hours or more. DC Fast charging stations are being more sparsely distributed across the Houston area, and are positioned to serve as de facto range extenders rather than as part of a regular charging routine.

2.3 Intercity EV Infrastructure Planning within Texas

U.S. DOE's EV Project was also implemented in the Dallas/Fort Worth metropolitan area, 240 miles north of Houston, but this effort was conducted separately from that in Houston. In 2012, U.S. DOE's Clean Cities Initiative provided funding to the Center for the Commercialization of Electric Technologies to develop a Texas Triangle Plug-in Electric Vehicle Readiness Plan, covering the triangle created by Houston, Dallas-Fort Worth, and San Antonio and linked by Interstates 45, 10, and 35. The Plan represents a noteworthy step toward EV infrastructure deployment between major Texas cities. The plan includes analysis of:

- State-level legislative and regulatory issues.
- Barriers to plug-in electric vehicle (PEV) readiness in small and mid-size cities in the Texas Triangle, and suggestions for overcoming them (including city model ordinances, permitting processes, and training to promote PEV charging stations along the corridors).
- Electric utility readiness to address challenges and opportunities posed by PEVs, including grid-related issues and management through policy mechanisms and alternative rate plans.
- Feasibility of connecting the larger urban areas with PEV charging infrastructure along the interstate corridors between them.

- How to provide a state-focused noncommercial and reliable source of PEV information (such as the resulting website of Texas-focused EV resources.
<https://sites.google.com/site/texastriangleev2/>)
- Longer-term “beyond readiness” considerations.

The plan’s basic conclusion is that without specific action and investment, EV charging infrastructure will not grow sufficiently over the next five years for drivers of battery electric vehicles (BEV) to comfortably make intercity trips between the major cities in the Texas Triangle. The plan identifies specific recommendations for addressing this gap and other challenges relating to the growth of EV infrastructure in the region⁴⁶.

2.4 Infrastructure Development

The Houston EV Project completed EV Charging Infrastructure Deployment Guidelines for the Greater Houston area in December of 2010, in order to organize and drive preparations for the coming introduction of the Nissan LEAF, Chevy Volt, Ford Focus EV, and other PEVs issued by major manufacturers in the Houston region.

ECOTality’s stated goal in the Houston EV Project was to install a minimum of 200 EV public charging stations across the city. The website of the Blink charging network lists 147 charging locations in Greater Houston as of September 2014, with each station having one or multiple charging units. The City has also worked with companies GRIDbot and ChargePoint to install charging equipment throughout the region.

Unique to Houston, the *eVgo* initiative launched by Houston-based energy company NRG Energy is building the nation’s first completely privately-funded, publicly-accessible network of at least 50 co-located Level 2 and DC Fast chargers at key locations across the greater Houston area. Target sites for deployment include shopping and business districts, multi-family and workplace parking areas, as well as along all major freeways from downtown Houston to approximately 25 miles from the city center⁴⁷. 27 stations are listed as operational on the eVgo website as of September 2014⁴⁸.

⁴⁶ “Overview – Texas Triangle Plug-In Electric Vehicle Readiness Plan,” 2011. Center for the Commercialization of Electric Technologies. http://www.electrictechologycenter.com/texas_triangle_project.html

⁴⁷ Micro-Climate Plan, p. 2.

⁴⁸ <http://www.evgonetwork.com/>



Figure A 7: A map of NRG’s planned eVgo DC Fast charging network in Greater Houston.

A definitive number of electric vehicle charging stations throughout the Greater Houston area is not currently tracked in any public database, making it difficult to report on their overall prevalence. However, as of September 2014, U.S. DOE’s Alternative Fuels Data Center—which maintains a non-exhaustive list of EV charging equipment across the country—documents 559 publicly-accessible EV charging stations across Texas, 96 of which are located within 25 miles of downtown Houston⁴⁹. Meanwhile, ChargePoint’s website lists more than 250 individual charging ports available to the public in the greater Houston area, including those in the ChargePoint, Blink, CarCharging, and eVgo networks. The Greater Houston region faces the challenge of standardizing and communicating information about the variety of charging station locations and technologies available. Many current EV charging networks require a subscription to use, and not all types of chargers work universally with all models of electric vehicles.

Houston’s plans project the eventual installation of up to 1,000 publicly accessible Level 2 charging stations, and up to 750 DC Fast chargers, installed in the greater Houston area by 2020⁵⁰.

2.5 Municipal Fleet Leadership

The City of Houston has leveraged its large municipal fleet to show leadership and advance EV vehicle and infrastructure deployment. In 2009, the City launched *Houston Drives Electric*, a city-wide electric vehicle initiative⁵¹. Through this initiative, the City of Houston worked with Reliant Energy in 2010 to convert 15 Toyota hybrid vehicles into plug-in hybrid electric vehicles

⁴⁹ Electric Vehicle Charging Station Locations. http://www.afdc.energy.gov/fuels/electricity_locations.html

⁵⁰ Micro-Climate Plan.

⁵¹ “Mayor Annise Parker and Partners Announce Launch of Houston Drives Electric,” 2011. Green Houston. <http://www.greenhoustontx.gov/ev/20110908.html>

and integrate them into the city fleet. The City also built a one-to-one charging infrastructure for these vehicles, along with two home charging stations⁵². In 2011, the City received a grant from the State Energy Conservation Office (SEO) to partially fund the purchase of 25 Nissan LEAF all-electric vehicles, and worked with ECOtality to install dozens of additional charging stations, some fleet-only and some open to the public⁵³.

In August 2012, in order to further expand the role of electric vehicles in the municipal government, the City launched a municipal electric vehicle fleet car-sharing program in partnership with Zipcar. The program began with an initial 50 city-owned fleet vehicles and in September 2013 was expanded to an additional site⁵⁴.

2.6 Other Factors Affecting EV Infrastructure Deployment in Texas

- The City of Houston frames the Greater Houston Area's new and resilient electric power grid relative to many U.S. cities, along with active smart-grid initiatives in the area, as potential boons to the feasibility of large EV and charging station deployment in the region.
- Some state-wide policy initiatives relating to electric vehicles have emerged. Texas offers a \$2,500 rebate on alternative-fuel vehicles—including electric vehicles under 8,500 pounds—that were purchased after September 1, 2013⁵⁵.
- Although not a law specifically targeting electric vehicles, Texas Occupations Code (TEX OC. CODE ANN. § 2301.476) prevents electric automaker Tesla from selling vehicles directly to the public in the state of Texas because it has no franchised dealer relationships in the state (http://www.teslamotors.com/advocacy_texas). While individual customers may purchase Tesla vehicles in other states or have them delivered through a complicated workaround, the law does effectively limit the ability of a leading electric vehicle manufacturer to grow in the state.

⁵² Rocky Mountain Institute (RMI). http://www.rmi.org/pgr_houston_texas

⁵³ "Houston Drives Electric." Green Houston. <http://www.greenhoustontx.gov/ev/houstondriveselectric.html>

⁵⁴ "The City of Houston Expands Its Shared Motor Pool Program, FleetShare," 2012. PR Newsire. <http://www.prnewswire.com/news-releases/the-city-of-houston-expands-its-shared-motor-pool-program-fleetshare-224419731.html>

⁵⁵ "Texas Laws and Incentives." U.S. DOE. <http://www.afdc.energy.gov/laws/laws/TX>

3. CASE STUDY: NORTH CAROLINA GREATER CHARLOTTE REGION

3.1 Overview

The nine-county greater Charlotte Region encompasses 74 municipalities and is home to North Carolina's largest city, as well as nearly 2 million people, representing nearly 25 percent of the state population. The region's population is projected to be at least 3.5 million people within 20 years⁵⁶.



Figure A 8: The nine-county Greater Charlotte region of North Carolina

Greater Charlotte—also known as Centralina—possesses a number of attributes that may support significant growth in electric vehicle (EV) adoption in the region⁵⁷:

- High projected population growth.
- High density of hybrid vehicle ownership, a leading indicator of consumer interest in plug-in electric vehicles (PEVs).
- A strong local business community, including the headquarters of 10 Fortune 500 companies and many energy-focused businesses.
- Local electric utilities and cooperatives engaged with the EV industry.
- Municipal governments proactively engaged on EV issues.



Figure A 9: NC PEV Readiness Initiative, <http://go4pev.org/>

⁵⁶ Greater Charlotte PEV Readiness Plan. <http://www.advancedenergy.org/transportation/ncpev/docs/GreaterCharlottePEVReadinessPlan-Version1.1-February%202013.pdf>

⁵⁷ Greater Charlotte PEV Readiness Plan.

3.2 Focus of Planning Efforts

Coordination and planning for electric vehicle readiness in North Carolina has happened on multiple levels. At the state level, the North Carolina Department of Commerce partnered with Advanced Energy—a nonprofit energy-focused planning, technical, and engineering services firm—to form the North Carolina Plug-in Electric Vehicle Taskforce (NC PEV Taskforce). The taskforce and the U.S. DOE-funded NC PEV Readiness Initiative—Plugging in from Mountains to Sea (M2S)—co-led the development of the Plug-In Electric Roadmap for North Carolina⁵⁸, written for the many and diverse stakeholders working to advance the EV market and infrastructure in North Carolina.

In a parallel process, M2S also supported the development of targeted community readiness plans for four key areas of the state: the greater Charlotte area, the greater Asheville area, the Piedmont Triad (including Winston-Salem and Greensboro), and the greater Triangle area (Raleigh, Durham, and Chapel Hill). Topical working groups assembled by M2S considered specific priority areas of policy, codes and standards; vehicles; charging infrastructure; education and outreach; and incentives and economic development. The findings and recommendations of the working groups informed both the state-level and community-level readiness plans.

In greater Charlotte, local EV community readiness planning was led by the Centralina Clean Fuels Coalition, which operates as part of the Centralina Council of Governments and has administered U.S. DOE's Clean Cities initiative in the greater Charlotte region since 2004.

To further support the Centralina region's planning efforts, the Centralina Clean Fuels Coalition established the greater Charlotte Regional Electric Vehicle Advisory Committee (REVAC) in the fall of 2009. REVAC consisted of stakeholders considered key to EV deployment in the nine-county area. As part of the subsequent community-wide EV planning efforts, the committee identified four key barriers to deploying a network of charging stations that would advance PEV adoption:

1. Lack of DC Fast charge stations in and between metro areas.
2. Lack of awareness of existing charging infrastructure.
3. Cost of installing electric vehicle charging infrastructure.
4. Absence of charging station infrastructure within long-range transportation plans.

⁵⁸ Plug-In Electric Roadmap for North Carolina.

http://www.advancedenergy.org/transportation/ncpev/docs/NCPEVRoadmap_February2013.pdf

3.3 Infrastructure Development

Overall electric vehicle charging station figures are difficult to obtain, as no public database definitively tracks all installation locations. The U.S. DOE's Alternative Fuels Data Center does track many sites, listing 219 stations as of September 2014 – 59 of them within 25 miles of Charlotte. However, many private charging networks maintain their own sites independently, and may not be listed on the AFDC site. At the time of the greater Charlotte PEV Readiness Plan's assessment in February 2013, the plan authors tallied 152 EV charging stations installed at publicly available locations in greater Charlotte, and an additional 112 at private corporations for employees.

One challenge for the greater Charlotte region, as for the entire country, will be how to standardize and communicate information about the variety of charging station locations and technologies available: many current EV charging networks require a subscription to use, and not all types of chargers work universally with all models of electric vehicles. According to the co-coordinator of the Centralina Clean Fuels Coalition, this issue of interoperability of charging infrastructure—as well as of the technological standards themselves, which is an issue especially for DC Fast chargers—is among the main challenges facing the further deployment of EV infrastructure and market uptake in the near future. Reflecting this compatibility in highway signage is a related challenge, and standard signage design for EV charging infrastructure will not solve this issue on its own⁵⁹.

3.3.1 Notable Individual EV Initiatives in Greater Charlotte

Several individual municipalities and businesses in the greater Charlotte region have introduced small numbers of PEVs and charging stations. Among the more sizeable initiatives are:

- The Power2Charlotte campaign was launched by the City of Charlotte to promote energy efficiency awareness and action across the city, funded by an Energy Efficiency Conservation Block Grant (EECBG) from U.S. DOE. One of the campaign's 16 projects focused on electric vehicles and provided \$275,000 for the purchase of eight electric vehicles for the City's fleet, along with the installation of 26 electric vehicle charging stations at seven locations around the City. Free EV charging at these stations was available to the public through June of 2013, and they subsequently remain open to the public for a fee⁶⁰.
- In the summer of 2013, Nissan North America committed to funding the deployment of 30–40 DC Fast charging stations in North Carolina, with aspirations to connect Asheville, Charlotte, and the Raleigh-Durham area. Nissan is partnering with Brightfield Transportation Solutions to design and install 20 DC Fast chargers and 40 Level 2

⁵⁹ Personal communication with Sean Flaherty, Co-Coordinator, Centralina Clean Fuels Coalition, September 2013.

⁶⁰ "Electric Vehicles and Charging Stations." Power2Charlotte. <http://www.power2charlotte.com/energy-initiatives/catalyst-projects/electric-vehicle-charging-stations.aspx>

charging stations, focusing on public space and municipal locations, and drawing on the NC PEV Roadmap for assistance in siting. The additional stations will be developed with Advanced Energy and sited at private-sector locations, based on certain conditions to ensure their usefulness and accessibility to the public⁶¹.

- North Carolina-based Duke Energy, the largest electric utility in the United States, committed in 2009 to transition all new vehicle purchases to PEVs by 2020⁶². Duke Energy is also engaging with EV development extensively in other ways, as covered in the section titled “Engaged Electric Utilities,” below.

3.4 Electric Vehicle Deployment in Greater Charlotte – By the Numbers

Highway-ready electric vehicles have been available for purchase in the greater Charlotte region since September 2011. Vehicle registration data from the North Carolina Department of Motor Vehicles shows that between August 2012 and March 2014, the number of PEVs registered in the region increased from 191 to 544, representing a 101-percent annualized increase. In the same period, the number of PEVs registered in North Carolina increased from 719 to 2,319, corresponding to a 118-percent annualized increase⁶³.

The Electric Power Research Institute (EPRI) projects that the nine-county greater Charlotte region will have 15,000 PEVs in service by the end of 2020 (out of 94,000 state-wide) and more than 125,000 (out of 768,000 state-wide) on the roads by 2030⁶⁴.

3.5 Policy Support for EVs

Although most action on EV deployment in North Carolina has occurred outside of the policy realm, a few policy initiatives from governance bodies, both within and beyond the Centralina area, have relevance to EV deployment. Among them:

3.5.1 State level

- PEVs in North Carolina are exempt from state emissions inspection requirements⁶⁵.
- PEVs in the state are permitted to use High Occupancy Vehicle (HOV) lanes on highways no matter their occupancy⁶⁶.

⁶¹ Personal communication with Sean Flaherty, September 2013.

⁶² “Going Electric,” Duke Energy. <http://www.duke-energy.com/plugin/pev-industry-initiatives.asp>

⁶³ Data spreadsheet and personal communication from Sean Flaherty, Co-Coordinator, Centralina Clean Fuels Coalition, September 2014.

⁶⁴ Greater Charlotte PEV Readiness Plan.

⁶⁵ “North Carolina Laws and Incentives for Exemptions.” U.S. DOE. <http://www.afdc.energy.gov/laws/laws/NC/incentive/3239>

⁶⁶ Ibid.

- The Local Government Federal Credit Union offers green vehicle loans to purchase qualified new and used fuel-efficient vehicles, including electric vehicles. The loan interest rates are 0.5 percent lower than traditional new or used vehicle loan rates⁶⁷.

3.5.2 Municipal Level

Mecklenburg County, which includes Charlotte, maintains a Trade Internet Permitting system that has been modified to include EV charging station permits. The system enables contractors to obtain permits in approximately 20 minutes, and these permits can be flagged specifically to EV charging equipment, to enable better tracking of anticipated impact on the power grid⁶⁸. Initial efforts are underway in the region to have the relevant electric utility automatically notified when a new permit is approved through this process, in order to better enable grid load planning⁶⁹.

3.6 Notable Public Communication and Stakeholder Training Initiatives

Many of the greater Charlotte EV planning actions included some public-communications aspects.

- The Centralina Clean Fuels Coalition created a website promoting and providing information on electric vehicles in the greater Charlotte region. The website hosts basic information about EV and readiness checklists, and serves as a central point of information for a variety of EV stakeholders in greater Charlotte, including individuals, businesses and fleet-owners, and government officials⁷⁰.
- Charlotte's Power2Charlotte campaign, in addition to providing funding for the installation of EV charging stations and the municipal purchase of PEVs, included the development of a website, maintained by the city after the end of the grant period, promoting and providing basic information about EV availability and infrastructure in the city⁷¹.



Figure A 10: Go4PEV.org, <http://go4pev.org/>

⁶⁷ “State Hybrid and Electric Vehicle Incentives,” 2013. National Conference of State Legislatures. <http://www.ncsl.org/issues-research/energyhome/state-electric-vehicle-incentives-state-chart.aspx#table>

⁶⁸ Greater Charlotte PEV Readiness Plan.

⁶⁹ Personal communication with Sean Flaherty, September 2013.

⁷⁰ <http://go4pev.org/>

⁷¹ <http://www.power2charlotte.com>

- Duke Energy maintains a PEV-oriented website that provides customers and the general public with substantial information about EVs and relevant Duke Energy programs for EV-owner utility customers⁷².

Additionally, many stakeholder groups have recognized the benefit of targeted outreach to key relevant stakeholders by hosting specialized training sessions. Among these:

- In July 2012, the Centralina Clean Fuels Coalition hosted a technical training for regional municipal officials on EV technology, code requirements, permitting, and design recommendations for EV charging equipment in municipalities⁷³.
- Advanced Energy, Duke Energy, and the North Carolina Community College system partnered to develop and host multiple hands-on training sessions throughout the state that prepare first responders to protect themselves and the public in the event of an emergency involving a PEV⁷⁴.
- Advanced Energy has also hosted specific training sessions on issues specific to planning for electric vehicles in municipal fleets⁷⁵.

3.7 Engaged Electric Utilities

Business-community engagement with EV developments in North Carolina extends to the state's three investor-owned electric utilities, all of which have taken substantial steps toward EV readiness⁷⁶. Duke Energy Carolinas, Duke Energy Progress (a subsidiary of Duke Energy after a summer 2012 merger, formerly Progress Energy), and Dominion Power are all taking extensive measures, including:

- Conducting research and EV pilot programs to evaluate charging technologies, study charging behaviors of PEV drivers, and better understand the likely impacts on the grid due to the proliferation of charging equipment.
- Recognizing the need to modify rate plans to incentivize off-peak charging and minimize grid impacts.

⁷² "Plug-in Electric Vehicles." Duke Energy. <http://duke-energy.com/plugin>

⁷³ "PEV Technical Training – Code and Permitting in Concord, NC (07/17/12), 2012. Centralina Clean Fuels Coalition. <http://vimeo.com/45990526>

⁷⁴ "Teaching Emergency First Responders about Electric Vehicles," 2012. Duke Energy. <http://www.duke-energy.com/youtility/blog/?post=teaching-emergency-first-responders-about-electric-vehicles>

⁷⁵ "Free Training Event: Understanding and Planning for Plug-In Electric Vehicles," 2013. NCPEV. <http://www.advancedenergy.org/portal/ncpev/blog/news/?p=224>

⁷⁶ Greater Charlotte PEV Readiness Plan.

- Exploring approaches to data-collection and even automatic utility notification of new EV charging equipment installation.
- Modifying internal documents and processes, such as customer service plans and communications materials, to be ready for more widespread EV adoption.

Preparing to eventually invest in grid infrastructure improvements as needed, although they see the near-term grid impact of EV growth to be minimal.

4. CASE STUDY: CALIFORNIA BAY AND MONTEREY BAY AREA

4.1 Overview

Northern California's San Francisco Bay is at the center of nine counties—together often known simply as the “Bay Area”—that include the metropolitan areas of San Francisco, Oakland, and San Jose, as well as many smaller municipalities. The Bay Area is home to more than 7 million people.

Immediately south along the Pacific Coast lies Monterey Bay, surrounded by Monterey, San Benito, and Santa Cruz counties. This region, known as the Monterey Bay Area, has a combined population of approximately 700,000.

The Bay Area Air Quality Management District (BAAQMD) is the public agency entrusted with regulating stationary sources of air pollution in the Bay Area. BAAQMD has led or coordinated much of the electric vehicle readiness planning work for the Bay Area and Monterey Bay Area.

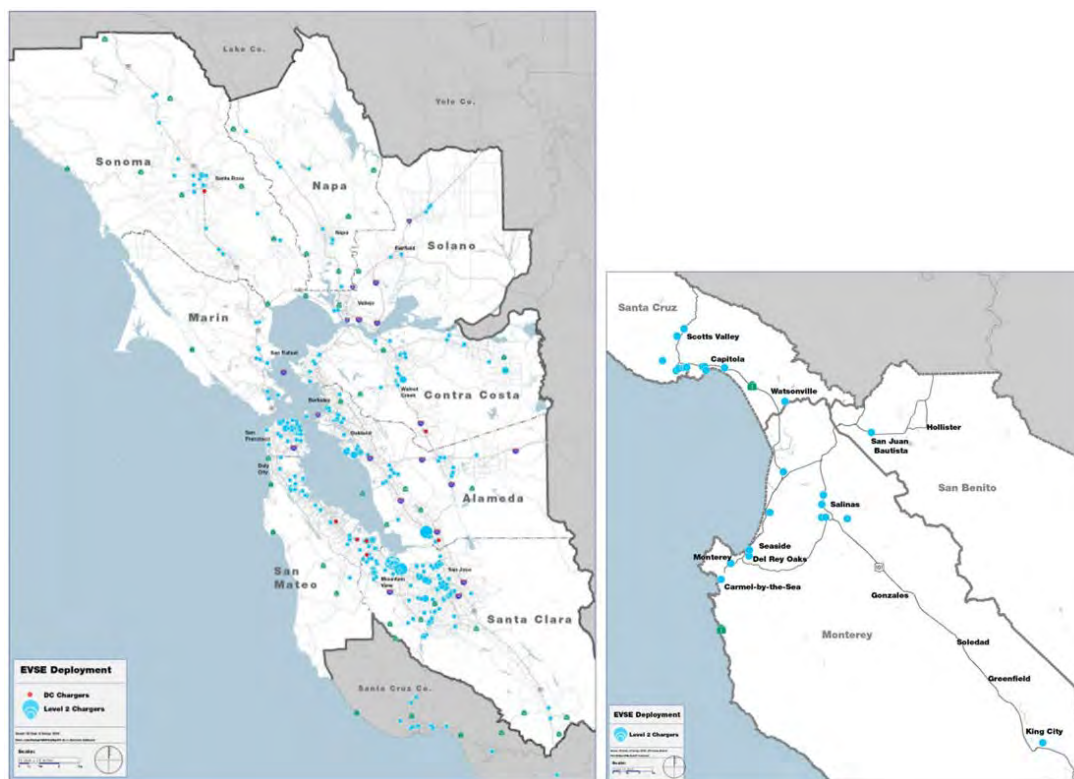


Figure A 11: Bay Area and Monterey Bay Areas⁷⁷

⁷⁷ Bay Area and Monterey Bay Area Plug-In Vehicle Readiness Plan: Background and Analysis, 2012. Bay Area Air Quality Management District (BAAQMD).

4.2 Focus of Planning Efforts

Efforts to support the adoption of electric vehicles (EVs) in California—the largest automotive market in the nation—have been supported by organizations at a variety of statewide, regional, and municipal levels.

Accelerated planning at the combined Bay Area and Monterey Bay Area level entered its modern stage in 2011 when BAAQMD, the South Coast Air Quality Management District, and the California Plug-In Electric Vehicle Collaborative submitted a joint application for funding from the U.S. Department of Energy (DOE) for plug-in electric vehicle (PEV) readiness planning for the state of California. As part of the support from DOE, BAAQMD was awarded \$300,000 to conduct EV readiness work in the combined Bay Area and Monterey Bay Area. The California Energy Commission (CEC) also contributed grants totaling \$200,000 to support the work⁷⁸.

This effort culminated in BAAQMD publishing the *Bay Area and Monterey Bay Area Plug-in Electric Vehicle (PEV) Readiness Plan* in late 2012⁷⁹. The plan includes:

- An analysis of existing PEV ownership.
- An analysis of barriers to further PEV deployment, ongoing management of infrastructure, and discussion of strategies to eliminate barriers.
- Identification of potential sites for regional charging infrastructure.
- Regional guidelines for PEV deployment, addressing the implications for areas such as zoning, parking rules, and local ordinances; building codes; construction, permitting, and inspection; training and education of key stakeholders and of consumers; and grid and utility impacts of PEV deployment.

In August 2012, BAAQMD also released an additional document, the *Bay Area and Monterey Bay Regions Local Best Practices Document*, to provide more specific guidance to cities, counties, and other local governments in the region interested in making their communities better prepared for the deployment of PEVs⁸⁰. This work complements that of the *Ready, Set, Charge*

<http://www.baaqmd.gov/~media/Files/Strategic%20Incentives/EV%20Ready/Summary%20PEV%20Readiness%20Plan%20FINAL.ashx>

⁷⁸ “About the PEC Deployment Planning Process.” Bay Area Air Quality Management District.
<http://www.bayareapevready.org/participate/process/>

⁷⁹ *Bay Area and Monterey Bay Area Plug-In Vehicle Readiness Plan*, 2012. BAAQMD.
<http://www.baaqmd.gov/~media/Files/Strategic%20Incentives/EV%20Ready/Summary%20PEV%20Readiness%20Plan%20FINAL.ashx>

⁸⁰ *Bay Area and Monterey Bay Area Regions Local Best Practices Document*, 2012. BAAQMD.
<http://www.bayareapevready.org/assets/Best-Practices-Documents-FINAL-online.pdf>

California! initiative led by the Association of Bay Area Governments (ABAG). In 2011, ABAG published its *Guide to EV Ready Communities*⁸¹, which provides local officials a consistent framework for EV infrastructure deployment and guidelines on key challenges and questions facing local governments.

The *Bay Area and Monterey Bay Area PEV Readiness Plan*, as a high-level regional document, did not include a detailed siting plan for PEV infrastructure in the Monterey Bay tri-county region, nor did it provide locally-specific recommendations for PEV readiness. Accordingly, the Monterey Bay Electric Vehicle Alliance, the local not-for-profit organization Ecology Action, and the Monterey Bay Air Pollution Control District jointly sought and received additional funding from CEC to address these needs. These organizations created the Monterey Bay Plug-in Electric Vehicle Coordinating Council (MB-PEVCC) to oversee the development and implementation of the *Monterey Bay PEV Readiness Plan*, which was released in July 2013. The plan includes extensive analysis and recommendations for facilitating EV infrastructure development and market adoption in the Monterey Bay Area⁸².

Several additional organizations in the Bay Area and Monterey Bay region are leading or assisting efforts to support PEV deployment through education, advocacy, and coordination among government agencies, researchers, utilities, and members of the PEV industry. The planning documents described above cover some of the involvement of these organizations.

4.3 Infrastructure Development

Regional agencies and a variety of EV service providers have responded to consumer demand for public EV charging infrastructure with a variety of projects, although exact installation figures are difficult to determine and are not exhaustively tracked by any single entity. The *Bay Area and Monterey Bay Area PEV Readiness Plan* assessed 11 existing EV charging infrastructure deployment initiatives in the region and calculated approximately 4,000 residential Level 2 chargers, 1,500 non-residential Level 2 chargers, and 123 DC Fast chargers in the Bay Area and Monterey Bay Area as of November 2012⁸³. However, not all of these locations are necessarily available to the general public. As of September 2014, the U.S. DOE's Alternative Fuels Data Center's non-exhaustive Alternative Fueling Station Locator showed more than 500 publicly available charging station locations in the Bay Area.

⁸¹ *Ready, Set, Charge California: A Guide to EV-Ready Communities*, 2011. ABAG. <http://www.rmi.org/Content/Files/Readysetcharge.pdf>

⁸² *Plug-In Electric Vehicle Readiness Plan for Monterey, Santa Cruz, and San Benito Counties*, 2013. MB-PEVCC and Monterey Bay Air Pollution Control District. <http://www.mbeva.org/wp-content/uploads/2013/06/Monterey-Bay-PEVCC-Readiness-Plan-Part-1.pdf>

⁸³ *Bay Area and Monterey Bay Area PEV Readiness Plan: Background & Analysis*.

A separate analysis in the *Monterey Bay PEV Readiness Plan* tallied 75 public charging stations available within the three-county Monterey Bay area as of June 1, 2013, including 51 Level 2 and 31 Level 1 charging units⁸⁴.

Initiatives continue to further expand the publicly available charging network. In June 2013, BAAQMD allocated \$1 million for a DC Quick Charger Program to support the expansion of the Bay Area's publicly available network of DC Fast chargers. The program provides up to \$20,000 per DC quick charger installed that meets the program requirements, including a base award amount per qualifying charger installed and a bonus award amount to be paid during operation for any station that meets or exceeds minimum usage requirements⁸⁵.

Some inter-city infrastructure development efforts are also underway. CEC has awarded more than \$17.4 million in grants to deploy about 4,500 Level 1 and 2 plug-in electric vehicle charge points, 49 DC Fast chargers, and up to 600 upgrades to existing legacy chargers across the state. Although this deployment of residential, commercial, workplace, fleet, and corridor chargers is concentrated in the regions around four cities—San Diego, Los Angeles, San Francisco, and Sacramento—it also includes placement of DC Fast charging stations on inter-regional highway corridors⁸⁶.

4.4 Electric Vehicle Deployment

The Bay Area has the highest number of electric vehicles deployed among the 22 regions participating in U.S. DOE's national EV Project. As of November 2012, more than 5,100 rebates had been issued for light-duty PEVs in the 12-county combined Bay Area and Monterey Bay Area regions under California's Clean Vehicle Rebate Project. This figure represents a minimum number of electric vehicles in the region at that time, because some PEVs were not initially eligible for the rebate, or may not have taken advantage of the rebate. Although the 12 counties comprise approximately 17 percent of California's population, the adoption rate of PEVs is approximately 40 percent of all PEVs sold across the state⁸⁷.

The California Plug-in Electric Vehicle Collaborative reports just over 100,000 electric vehicles sold across the state of California from 2011 through August 2014⁸⁸. This represents a more than doubling above year-end 2013 figures, indicating strong acceleration of PEV sales across the state. The Bay Area and Monterey Bay Area PEV Readiness Plan estimates 100,000 PEVs in the 12-county area by 2020, and over 230,000 by 2025.

⁸⁴ Charging Station Locations, MBEVA. <http://www.mbeva.org/charging-station-locations/>

⁸⁵ "DC Quick Charger Deployment Program," 2013. Bay Area Air Quality Management District. <http://www.baaqmd.gov/Divisions/Strategic-Incentives/Bay-Area-EV-Ready/DC-Quick.aspx>

⁸⁶ "Green Highways." Pacific Coast Collaborative. <http://www.pacificcoastcollaborative.org/priorities/transportation/Pages/GreenHighways.aspx>

⁸⁷ *Bay Area and Monterey Bay Area PEV Readiness Plan: Summary*.

⁸⁸ California PEV Collaborative. <http://www.evcollaborative.org/>

4.5 Policy Support for EVs

4.5.1 State-Level EV Policy Support

A wide range of state-level policies support and incentivize the growth of PEV adoption in California. Among them:

- In late September 2013, California Governor Jerry Brown signed into law a series of bills to support the expansion of EV ownership in the state. Three of the strategies for doing so are especially notable:
 - SB 359 provides over \$38 million to fund four programs that encourage green vehicle purchases of personal automobiles, trucks and buses, and fleet vehicles.
 - AB 1092 requires changes in buildings to be accompanied by the installation of infrastructure for electric vehicle charging in multi-family dwellings and non-residential places like businesses and shopping centers.
 - SB 454 requires all EV charging stations in the state to allow any vehicle to plug in and charge, and to accept credit card payments for charging station use, rather than requiring network membership and subscription fees as many providers currently do⁸⁹.
- PEVs in California are permitted to use High Occupancy Vehicle (HOV) lanes on highways, no matter their occupancy, and are exempt from tolls in High Occupancy Toll lanes⁹⁰.
- The state's Clean Vehicle Rebate Project (CVRP) offers rebates of up to \$2,500 for the purchase or lease of qualified light-duty zero-emission and plug-in hybrid vehicle models that have been certified or approved by the California Air Resources Board⁹¹.
- A 2011 amendment to the California Public Utilities Code clarified that a corporation or individual that owns, controls, operates, or manages a facility that supplies electricity for public use exclusively for the purpose of charging light-duty battery electric and plug-in hybrid electric vehicles, is not defined as a public utility and thus not subject to CPUC regulation as such⁹².

⁸⁹ "California's Sustainable Transport Incentives Leave Other States in the Stone Age," 2013. *Wired*. <http://www.wired.com/autopia/2013/10/california-bills-ev-ready/>

⁹⁰ "State and Federal Incentives." Monterey Bay Electric Vehicle Alliance. <http://www.mbeva.org/state-and-federal-incentives/>

⁹¹ Ibid.

⁹² California Assembly Bill 631, 2011. LegiScan. <http://legiscan.com/CA/bill/AB631/2011>

- A number of other state regulations require a certain degree of purchase or accommodation of alternative-fuel and zero-emissions vehicles, especially by state agencies, which serve to assist EV deployment state-wide⁹³.

4.5.2 Municipal EV Policy Support

Many municipalities have been considering and adopting amendments to permitting and inspection processes, building and zoning codes, and other local-level policies to ease the process of installing both residential and commercial electric vehicle charging equipment. Indeed, the adoption of EV-friendly local laws and codes was a major desired outcome of the regional PEV readiness planning efforts.

Some municipalities are innovating beyond the PEV readiness efforts of most others. Two examples in this region are in the southern Bay Area:

- San Jose is one of a handful of cities across California to offer free downtown parking to qualified electric vehicles⁹⁴.
- In September 2013, the City of Palo Alto made news for adopting a mandate that all new homes built within the city limits must be pre-wired to support EV charger installation⁹⁵.

4.6 Electric Utility Support for EVs

All major California utilities have PEV infrastructure programs in place that typically involved working with city officials to develop residential charging station procedures, planning for local infrastructure enhancements, and working in partnerships to pilot and demonstrate public infrastructure programs⁹⁶. Pacific Gas & Electric (PG&E), the electric utility serving the Bay and Monterey Bay Areas, also offers a discounted Experimental Residential Time-of-Use rate for electricity used for plug-in electric vehicle charging. The utility also provides substantial information about PEVs on its customer-facing website, along with an electricity cost estimator for various PEV models and detailed information about its alternative rate structures for PEV owners⁹⁷.

⁹³ “State and Federal Incentives.”

⁹⁴ “State Hybrid and Electric Vehicle Incentives,” 2013. National Conference of State Legislation (NCSL). <http://www.ncsl.org/issues-research/energyhome/state-electric-vehicle-incentives-state-chart.aspx#ca>

⁹⁵ “City of Palo Alto Mandates that All New Homes Come EV-Ready,” 2013. Plugincars.com <http://www.plugincars.com/city-palo-alto-ca-mandates-all-new-homes-come-ev-ready-128414.html>

⁹⁶ California Plug-In Electric Vehicle Collaborative. <http://www.evcollaborative.org/resources>

⁹⁷ Pacific Gas & Electric (PG&E). <http://www.pge.com/electricvehicles/>

4.7 Public Education and Training of Key Stakeholders

Many of the regional organizations involved in EV planning efforts maintain publicly useful information about EVs on their respective websites. Multiple initiatives across the state currently offer online and in-person training opportunities to educate stakeholders on the more technical aspects of PEV readiness and deployment. These efforts include:

- BAAQMD created and maintains the *Bay Area PEV Ready* website⁹⁸, which serves as a public access point for information on PEV basics, charging technology, funding and incentive programs, and EV-related workshops and events in the region.
- BAAQMD hosted six public informational sessions throughout the Bay and Monterey Bay Areas to share draft content of the PEV Readiness Plan and collect stakeholder input and feedback⁹⁹.
- U.S. DOE’s Clean Cities program developed a 30-minute online presentation for electrical contractors and inspectors regarding charging station residential charging installation. In the Bay Area, the three local Clean Cities coalitions—centered in San Francisco, the East Bay (Oakland), and Silicon Valley (San Jose)—have led and promoted various other training efforts in the region¹⁰⁰.
- The Electric Vehicle Infrastructure Training Program (EVITP) is a 24-hour course set up to train and certify electricians throughout California to install residential and commercial-scale charging station. The training program addresses the technical requirements to ensure that the equipment is properly installed and maintained, and also instructs stakeholders on issues related to charging station deployment. EVITP has sponsored events in the Bay Area, funded in part by a grant from CEC¹⁰¹.
- The Advanced Transportation Technology and Energy (ATTE) Initiative offers training courses at several community colleges throughout California, including the City College of San Francisco. Training includes an 8–16-hour course on PEVs and EV charging equipment¹⁰².

⁹⁸ “Bay Area PEV Ready,” Bay Area Air Quality Management District. <http://bayareapevready.org>

⁹⁹ “Draft Bay Area & Monterey Bay Plug-In Electric Vehicle Readiness Plan,” events held in 2012. Eventbrite. <http://pevreadinessplan.eventbrite.com/>

¹⁰⁰ “Bay Area and Monterey Bay Regions Local Best Practices Document.” <http://www.bayareapevready.org/assets/Best-Practices-Document-FINAL-online.pdf>

¹⁰¹ Ibid.

¹⁰² Ibid.

4.8 Emergency-Response Services

In 2011, AAA launched a pilot program in San Francisco offering roadside-charging emergency services in the form of a specialized truck with an on-board electric generator or lithium-ion battery pack. This service is also being tested in Los Angeles, Seattle, Portland, OR, Knoxville, TN, and Tampa Bay, FL¹⁰³. The truck supports both DC Fast charging and Level 2 AC charging, and provides up to 15 minutes of charge time to a member with a discharged electric vehicle¹⁰⁴.



Figure A 12: AAA Emergency Roadside Mobile Electric Vehicle Charging

¹⁰³ <http://www.dvice.com/2013-3-21/aaa-unveils-emergency-charging-truck-electric-cars>

¹⁰⁴ <http://newsroom.aaa.com/2011/07/ev-charging-statio/>