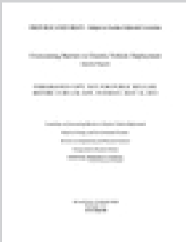

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Overcoming Barriers to Electric-Vehicle Deployment
Interim Report

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Committee on Overcoming Barriers to Electric-Vehicle Deployment

Board on Energy and Environmental Systems

Division on Engineering and Physical Sciences

Transportation Research Board

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Preface

Electric vehicles hold many promises—from reducing dependence on imported petroleum to decreasing greenhouse-gas emissions. However, there are many barriers to their mainstream adoption regardless of incentives and enticing promises to solve difficult problems. The vehicles have some technologic limitations, such as restricted electric range and the long time required for battery-charging; they cost more than conventional vehicles; and they require an infrastructure for charging the battery. Given the concerns regarding barriers, Congress asked the Department of Energy to commission a study by the National Research Council (NRC) to investigate the barriers and recommend ways to mitigate them.

In this short interim report, the Committee on Overcoming Barriers to Electric-Vehicle Deployment identifies infrastructure needs for electric vehicles, the barriers to deploying that infrastructure, and optional roles for the federal government in overcoming the barriers; it also presents an initial discussion of pros and cons of the optional roles. The committee first addresses needs and barriers associated with the adoption of plug-in electric vehicles from the customer perspective. It then discusses the needs for and barriers to charging and the electric grid. Those issues and many others will be developed further in the committee's final comprehensive report, which is due in late summer 2014.

The present report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following for their review of this report:

Andrew Brown, Jr., NAE,[1] Delphi Corporation,
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Jeremy J. Michalek, Carnegie Mellon University,
John O'Dell, Edmunds.com, and
Dan Reicher, Stanford University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by the review coordinator, Maxine Savitz, NAE, Honeywell Inc. (retired), and the review monitor, Elisabeth Drake, NAE, Massachusetts Institute of Technology (retired). Appointed by NRC, they were responsible for making certain that an independent examination of the report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with

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the committee and the institution. The committee gratefully acknowledges the following for their presentations:

Marcus Alexander, Electric Power Research Institute,
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Michael Tamor, Ford Motor Company,
Joe Thompson, Nissan North America,
Jacob Ward, Department of Energy, and
Jason Wolf, Better Place.

The committee is also grateful for the assistance of the NRC staff in preparing this report. Staff members who contributed to the effort are Ellen Mantus and K. John Holmes, project co-directors; James Zucchetto, board director; Joseph Morris, senior program officer; Norman Grossblatt, senior editor; Michelle Schwalbe, program officer; David Cooke, associate program officer; and Alice Williams, senior program assistant.

I especially thank the members of the committee for their efforts throughout the development of this report.

John Kassakian, *Chair*
Committee on Overcoming Barriers to Electric-Vehicle Deployment

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Summary

The electric vehicle offers many promises—increasing U.S. energy security by reducing petroleum dependence, contributing to climate-change initiatives by decreasing greenhouse gas (GHG) emissions, stimulating long-term economic growth through the development of new technologies and industries, and improving public health by improving local air quality. There are, however, substantial technical, social, and economic barriers to widespread adoption of electric vehicles, including vehicle cost, small driving range, long charging times, and the need for a charging infrastructure. In addition, people are unfamiliar with electric vehicles, are uncertain about their costs and benefits, and have diverse needs that current electric vehicles might not meet. Although a person might derive some personal benefits from ownership, the costs of achieving the social benefits, such as reduced GHG emissions, are borne largely by the people who purchase the vehicles. Given the recognized barriers to electric-vehicle adoption, Congress asked the Department of Energy (DOE) to commission a study by the National Academies to address market barriers that are slowing the purchase of electric vehicles and hindering the deployment of supporting infrastructure. As a result of the request, the National Research Council (NRC)—a part of the National Academies—appointed the Committee on Overcoming Barriers to Electric-Vehicle Deployment.

The committee's analysis is to be documented in two reports—a short interim report focused on near-term options and a final comprehensive report. The present report fulfills the request for the short interim report that addresses specifically the following issues: infrastructure needs for electric vehicles, barriers to deploying the infrastructure, and possible roles of the federal government in overcoming the barriers; the report also includes an initial discussion of the pros and cons of the possible roles. This interim report does not address the committee's full statement of task and does not offer any recommendations because the committee is still in its early stages of data-gathering. The committee will continue to gather and review information and conduct analyses through late spring 2014 and will issue its final report in late summer 2014.

This report focuses on the light-duty vehicle sector in the United States and restricts its discussion of electric vehicles to plug-in electric vehicles (PEVs), which include battery electric vehicles (BEVs)[1] and plug-in hybrid electric vehicles (PHEVs). The common feature of these vehicles is that their batteries are charged by being plugged into the electric grid. BEVs differ from PHEVs because they operate solely on electricity stored in a battery (that is, there is no other power source); PHEVs have internal-combustion engines that can supplement the electric power train.[2]

Although this report considers PEVs generally, the committee recognizes that there are fundamental differences between PHEVs and BEVs. Given that PHEVs can switch over to gasoline when their batteries are depleted, the driving experience tends to be more familiar than that of BEVs, and they do not have the range issues of BEVs. Those differences might influence the type, number, and locations of charging infrastructure required to support the different vehicles. PHEVs have seen a substantial growth in sales over the last year, boosted largely by the existence of more models and range options. However, BEVs have also seen their share rise relative to that of conventional vehicles.

[1] The term *all-electric vehicle* (AEV) is sometimes used instead of BEV.
[2] PHEVs can use engines powered by various fuels. This report, however, focuses on those powered by gasoline because they are the ones available in the U.S. market.

Generally, the value proposition for a PHEV vs a BEV is determined by how well it meets a customer's needs and by how well its price matches what a customer is willing to pay. Because the market is still evolving, it is difficult to know whether PHEVs or BEVs will provide the best value proposition for most customers.

To identify the needs and barriers associated with PEV deployment, the committee considered the automobile manufacturers, which supply the vehicles to dealers; the customers, who purchase or lease the vehicles; the charging infrastructure, which allows the vehicles to connect to the electric grid and recharge their batteries; and the electric grid, which is the source of the power used for charging the vehicle batteries. The following sections provide the committee's findings and possible roles of the federal government in overcoming the identified barriers.

THE CUSTOMERS, MANUFACTURERS, AND DEALERS

Customers include individuals, households, and organizations, such as rental-car companies, corporations, and governments. The committee focused primarily on individuals and households because they make up the largest segment of potential buyers and because there might be more obstacles to their adoption of PEVs. It also considered barriers that automobile manufacturers and dealerships face in promoting the adoption of PEVs. Major findings and possible federal roles in overcoming barriers are presented below.

Finding: Most potential PEV customers have little knowledge of PEVs and almost no experience with them. Lack of familiarity with the vehicles and their operation and maintenance creates a substantial barrier to widespread PEV deployment.

Possible Federal Roles: Produce public-service announcements that showcase current PEV owners, describe the benefits of PEV ownership, and illustrate how a PEV meets various transportation needs; create marketing campaigns to help customers to understand incentives and that target audiences that have transportation needs that might fit PEVs; and provide ride-and-drive activities or demonstrations at high-visibility locations to familiarize the public with PEVs.

Finding: PEVs have higher purchase prices than comparable conventional vehicles. Research indicates that people heavily discount the value of future gains; sticker-price premiums typically will be difficult to overcome with fuel-savings promises alone.

Possible Federal Roles: Continue to provide economic incentives—such as continuing or extending tax credits or rebates—to encourage customers to buy PEVs; increase the tax on gasoline by increasing taxes on motor fuels or by instituting a broad-based carbon tax; and use the convening function to coordinate state and local incentives that would encourage PEV ownership and use, such as access to carpool lanes, parking benefits, and reduced vehicle registration or licensing fees. Some research has shown that purchase rebates can be more effective than income- tax credits.

Finding: Most BEVs have small driving ranges, and this could be a substantial barrier to their widespread adoption. However, commuting by electricity stored in vehicles should be feasible on a large scale in the United States given that some BEVs can routinely travel 40–80 miles on one charge and that nearly 70 percent of average daily travel is less than 40 miles and over 90 percent is less than 80 miles.

Finding: Few data on customer perceptions, attitudes, and behavior regarding PEVs are publicly available. Although some studies have examined those topics, further

research could help to determine how to structure effective programs and policies. Little research has been conducted to determine which government policies concerning PEVs are the most successful and why.

Possible Federal Role: Support research to obtain a better understanding of why potential customers would or would not purchase PEVs and how they have responded to various initiatives, programs, or incentives that are aimed at promoting widespread PEV adoption, including DOE's Clean Cities programs; and revise or adapt programs as information on their effectiveness is collected.

Finding: Few PEV model choices are offered to customers, and the variety offered does not meet the needs of all customers. However, sales of PEVs must increase to justify further investment by automobile manufacturers to diversify the products offered.

Possible Federal Role: Continue to support research on and development of electric-drive technologies to improve their performance and reduce their costs; reduced costs would encourage purchase and indirectly encourage the use of electric-drive technology in a variety of models.

Finding: Dealerships are independent franchises that are not owned or operated by the automobile manufacturers. Training and educating dealership personnel—salespersons, mechanics, financial specialists, and managers—entail substantial costs to a franchise. Given those costs, many dealerships do not appear to be fully prepared to explain PEVs and educate customers about them. As a result, there appears to be an information gap at the primary point of sales.

THE CHARGING INFRASTRUCTURE

Charging a PEV is analogous to filling the fuel tank of a conventional vehicle with gasoline, although at a much lower rate. PEVs can be "filled" at a variety of locations, including private residences and workplaces; thus, the electric analogue of a gas station is not likely to be the primary source of energy for a PEV. Furthermore, unlike a conventional vehicle, PEVs can be "filled" at different rates by using different charger types. Charging rate affects the length of time required to charge a PEV, the equipment and installation requirements, and the cost of providing charging at a particular location.

Most electric charging infrastructure is (and is likely to remain) at residences where PEVs are available for charging for the longest time. Because PEVs are also parked at workplaces for substantial periods on each workday, workplace charging is a promising option if practical ways can be found to provide the needed infrastructure. PEVs typically have much less time available for charging while parked in public places, but charging in public places may be feasible if fast charging is available, if a vehicle is parked for at least 4 hours, or if only a partial battery charge is needed.

In addressing issues about charging-infrastructure needs, the committee assumed that the goal was to maximize the fraction of miles fueled by electricity for light-duty vehicles. The committee recognizes that the goal influences the type, number, and location of charging infrastructure needed and that other potential goals, such as maximizing the number of PEVs on the road or maximizing the number of miles traveled by BEVs, might lead to different conclusions. In light of the committee's stated goal, it is indifferent to whether PEV electric miles are traveled by BEVs or PHEVs. The infrastructure needs and barriers and some options for overcoming the barriers at the various locations are offered below.

Finding: An overarching need for the deployment of all aspects of the PEV charging infrastructure is an understanding of the charging needs for PHEV and BEV drivers, how their needs might change in the future, and how they might change in

response to various policy initiatives. Those needs are affected by a variety of factors, including the types of PEVs on the road, travel patterns of these vehicles, and the costs of charging at different locations.

Possible Federal Role: Continue efforts to collect, analyze, and disseminate data on vehicle charging, PEV sales, and policy effectiveness. The resulting information could help to address the extent to which various charging options meet residential, workplace, and publicly accessible charging needs. It could also improve understanding of what policies are most effective in maximizing the fraction of electric miles traveled. The analysis could include research to understand the effects of installing charging infrastructure on economic and related activity.

Residential Charging

Finding: There are no serious technical barriers to the installation of charging infrastructure at most residences that have access to garages or carports. Charging at such residences would meet the needs of all foreseeable PHEVs and of most BEVs that have ranges of up to 100 miles. The main barriers to the widespread adoption of residential charging of PEVs appear to be the cost and the effort of installing the wiring and charging apparatus.

Possible Federal Role: Continue tax incentives and subsidies for installing charging infrastructure and encourage state and local governments to streamline permitting and to adopt building codes that require new construction to be PEV-charging-enabled.

Finding: Residential charging is problematic for residences that have access only to on-street parking, as might be the case for multifamily dwellings in high-density locations. Residential charging also might be problematic for those who rent their homes and therefore would not have authority to make structural changes to the property that would be required for installing a charger and possible electricity upgrades. An owner of a rental property could be reluctant to invest in charging equipment that might not be used by the next tenant. Thus, for those drivers who lack access to residential charging, the barriers might be partially overcome by having access to workplace or public-charging infrastructure.

Possible Federal Role: Encourage or subsidize local governments to establish dedicated parking spots or to install charging infrastructure that is publicly accessible.

Workplace Charging

Finding: Increasing the availability of workplace charging infrastructure offers a potentially important opportunity to encourage the adoption of PEVs. The workplace provides a place where vehicles are parked typically for at least 8 hours during the day. Over that time, even a low-power charger can add a useful amount of vehicle range. Important unknowns regarding workplace charging infrastructure are the potential effects and needs if and when much larger battery capacity becomes affordable; this might be particularly important in less densely populated areas. Another important unknown is how the use of workplace charging might depend on whether employees have to pay for it.

Possible Federal Roles: Offer a financial incentive, such as an accelerated depreciation schedule, so that businesses are more willing to offer workplace charging; exempt electricity provided by workplace charging infrastructure from being treated as a taxable benefit; work with utilities and their regulators to minimize special charges that might be incurred because of workplace charging; and support research on demonstration installations.

Publicly Accessible Charging

Finding: Publicly accessible charging infrastructure provides several important benefits, such as extending the electric range of all PEVs, relieving range concerns of BEV owners, and providing increased visibility of both PHEVs and BEVs. However, the high cost of installing public charging stations and the little revenue obtained from providing electricity present challenges for developing sustainable business models. In the near term, deploying publicly accessible charging infrastructure might require public-private partnerships or other forms of continued government support.

Possible Federal Roles: Provide incentives to demonstration projects that propose credible business models that could eventually be sustained when subsidies are no longer available; provide increased clarity and simplicity regarding regulatory compliance with such laws as the Americans with Disabilities Act; and incentivize landowners, retailers, and public agencies to offer host sites for installing charging infrastructure in key highway corridors.

Standardization of Charging Infrastructure

Finding: It is critical to standardize the many components of the charging infrastructure. Multiple plugs for fast chargers and the lack of standardization of payment methods for various charging networks are particularly problematic.

Possible Federal Role: Use the convening function to encourage standardization of charging plugs and payment methods. The committee recognizes that such standardization might restrain innovation, but increasing compatibility increases coverage of the whole charging infrastructure.

THE ELECTRIC GRID

Another important consideration for PEV deployment is the electric grid, which provides the electricity that powers PEVs. The mass deployment of PEVs would create a substantial new load for the electric grid, and how the power sector handles such a new load might affect the deployment of PEVs. This section presents the committee's findings regarding the electric grid.

Finding: The existing electric infrastructure does not present a barrier to the expansion of PEV technology in the United States given the projected growth of PEV use in the next decade. With the exception of a scenario in which PEVs are concentrated within an overburdened branch of the distribution system, no major physical barriers have been identified.

Finding: As PEVs account for a more significant share of total electricity consumption, the committee sees no barriers to provision of generation and distribution capacity to accommodate the growth through the normal processes of infrastructure expansion and upgrades in the electric-utility industry.

Finding: The current time-based rate structures (time-of-use or real-time pricing) available to most commercial and industrial customers and some residential customers provide an incentive to PEV owners and utilities in that they encourage charging at times when lower-cost generating capacity is available.

Finding: Regulating third-party entities (nonowner, nonutility charging-service providers) as utilities could increase operating costs and decrease business-model flexibility. Furthermore, the role and scope allowed to utilities (as opposed to third-party entities) in providing charging equipment are unclear.

Finding: The lack of access to or price premium for clean electricity could be a barrier to PEV adoption by vehicle owners who are seeking to mitigate their environmental impact. Overall, however, there is already a net benefit of using PEVs compared with using vehicles that have traditional internal-combustion engines given the existing mix of electricity-generation sources. The benefit can be increased by a continued transition to generation sources that have lower life-cycle emissions.

CONCLUDING REMARKS

Overall, the committee found that there are no serious technical barriers to the deployment of infrastructure at residences, workplaces, and publicly accessible locations. A substantial fraction of detached homes have much capacity for at least basic charging, although widespread deployment might face challenges in the case of multifamily housing and rental properties. Increasing the availability of workplace charging is an important infrastructure opportunity given that vehicles are typically parked at workplaces for at least 8 hours each day during the workweek. Workplace charging might also present a primary charging opportunity for those who lack access to residential charging. In the case of publicly accessible charging, the high installation costs and low revenue associated with providing electricity present challenges for developing sustainable business models and thus might require public-private partnerships or other forms of continued government support in the near term.

The committee has suggested a variety of possible roles for the federal government, some of which the federal government is already pursuing. Many of the activities suggested here could increase the public's familiarity with PEVs and encourage their adoption. Others could provide information that would help in designing effective policies and ensure that the PEV investment is working to increase the fraction of electric miles traveled. The disadvantages of the possible activities are that they require resources—time, money, or staff. The strain on federal resources emphasizes the need to understand which policies are most effective, what does not work, and the best ways to revise or restructure policies or programs to make them more effective. The committee's final report will explore those and other options further and will consider other barriers to PEV deployment, including technologic and economic ones.

1

Introduction

Reducing U.S. dependence on imported petroleum is an important step toward improving the nation's energy and economic security. Electric vehicles that derive all or some of their propulsion from an external electricity source have received critical attention in recent years because they have the potential to reduce petroleum consumption substantially given that light-duty vehicles account for nearly half the petroleum consumption in the United States today and that electricity is typically not generated from petroleum (EIA, 2012). Globally, the demand for electric vehicles is growing, and some countries see electric vehicles as an important element of their long-term strategy to meet environmental, economic, and energy-security goals. Although the electric vehicle holds many promises, there are also many barriers to its penetration into the mainstream market today. Some are technologic, such as the capabilities of current battery technologies that restrict driving range and increase purchase price compared with conventional vehicles; others are related to consumer behavior and attitudes; and still others are related to the need to develop a charging network to support the vehicles and to address the possible effects of the new charging network on the electric grid. Given the growing concerns surrounding the potential barriers, Congress in its 2012 appropriations for the Department of Energy (DOE) requested that DOE commission a study by the National Academies to identify market barriers that are slowing the purchase of electric vehicles and hindering the deployment of supporting infrastructure. As a result of the request, the National Research Council (NRC)—part of the National Academies—appointed the Committee on Overcoming Barriers to Electric Vehicle Deployment, which prepared this interim report.

HISTORICAL AND POLICY CONTEXT

The electric vehicle is not a new invention of the 21st century. In 1900, 28 percent of the passenger cars sold in the United States were electric, and about one-third of the cars on the road in New York City, Boston, and Chicago were electric (Schiffer et al., 1994). Mass production of an inexpensive gasoline-powered vehicle (the Model T), the invention of the electric starter for the gasoline vehicle (which eliminated the necessity of the hand-crank), a supply of readily affordable gasoline, and the development of the national highway system (which allowed long-distance travel), however, led to its demise (Schiffer et al., 1994). In the 1970s, interest in electric vehicles resurfaced with the Arab oil embargo and the emerging environmental and energy-security concerns, but interest over the next few decades waxed and waned as gasoline prices remained roughly constant. In the 1990s, interest in electric vehicles was revived by California's zero-emission-vehicle policies, but battery technology was not as advanced as it is today, the automobile industry did not support the initiative, and the program was delayed. The current administration's goal of putting millions of electric vehicles on the road, new federal carbon dioxide-emission and fuel-economy standards, and recent advances in battery and other technologies have refocused attention on electric vehicles.

The current movement to increase the number of electric vehicles on the road was initially spurred by the Emergency Economic Stabilization Act of 2008, which provided a $2,500 to $7,500 tax credit for the purchase of electric vehicles (Public Law 110-343, §205). The American Recovery and

Reinvestment Act of 2009 (Public Law 111-5, §1141) increased incentives for electric vehicles by increasing the types of vehicles that are eligible for a tax credit. It also appropriated $2 billion in grants for development of electric-vehicle batteries and related components (DOE, 2009) and $2.4 billion in loans for electric-vehicle manufacturing facilities (DOE, 2011). DOE has invested $400 million along with private funds to support infrastructure development, including demonstration projects involving 13,000 electric vehicles and 22,000 public and private charging points in 20 U.S. cities (DOE, 2011). The DOE Office of Energy Efficiency and Renewable Energy (DOE, 2013a) and several national laboratories, including Argonne National Laboratory (ANL, 2011, 2012, 2013) and the National Renewable Energy Laboratory (NREL, 2013), are conducting substantial research and development on electric-drive technologies for electric vehicles (NRC, 2013).

Various state-level efforts are aimed at increasing the number of electric vehicles on the road—such as customer incentives that include tax credits for vehicle purchase, access to carpool lanes, free public parking, and inspection exemptions—and at building the charging infrastructure, such as reimbursements and tax incentives for purchasing or leasing charging equipment and low-cost loans for projects (DOE, 2013b). California's Zero-Emission Vehicle (ZEV) requirements constitute a particularly important incentive because of the size of the California motor-vehicle market. Each motor-vehicle manufacturer's sales in the state are required to include at least a minimum percentage of ZEVs (vehicles that produce zero exhaust emissions of any criteria pollutant) and transitional ZEVs (vehicles that are capable of traveling some minimum distance solely on a ZEV fuel, such as electricity) (13 CCR § 1962.1 [2013]).

The policies that promote early electric-vehicle deployment are aimed at benefits beyond near-term reductions in petroleum consumption and pollutant emissions. The strategy is to speed the long-term process of conversion of the motor-vehicle fleet to alternative energy sources by exposing consumers now to electric vehicles, by encouraging governments and service providers to plan for infrastructure, and by encouraging the motor-vehicle industry to experiment with product design and marketing. Gaining a major market share for electric vehicles probably will require advances in technology to reduce cost and improve performance, but the premise of the early deployment efforts is that market development and technologic development that proceed in parallel will lead to earlier mass adoption than if we wait for technologic advances before beginning market development. The early deployment efforts also might speed technologic progress by maintaining visibility and interest in electric vehicles. The risk entailed by this strategy is that the benefits of electric-vehicle promotion might be diminished if the timing of promotion efforts is premature relative to the development of the technology.

THE PLUG-IN ELECTRIC VEHICLE AND ITS ECOSYSTEM

This report focuses on the light-duty fleet (passenger cars and light-duty trucks) in the United States and restricts its discussion of electric vehicles to plug-in electric vehicles (PEVs), which include battery electric vehicles (BEVs)[1] and plug-in hybrid electric vehicles (PHEVs).[2] The common feature of these vehicles is that they charge their batteries by plugging into the electric grid. The distinction between them is that BEVs operate solely on electricity stored in the battery (there is no other power source), and PHEVs have an internal-combustion engine that can supplement the electric power train.[3, 4]

[1] The term *all-electric vehicle* (AEV) is sometimes used instead of BEV.

[2] BEVs and PHEVs need to be distinguished from conventional hybrid electric vehicles (HEVs), such as the Toyota Prius that was introduced in the late 1990s. HEVs do not plug into the electric grid but power their batteries from regenerative braking and an internal-combustion engine. They are not included in the PEV category and are not considered further in this report.

[3] Several design architectures are available for PHEVs, and, depending on the design, the engine may be used to drive the vehicle directly or act as a generator to recharge the battery or both.

[4] PHEVs can use engines powered by various fuels. This report, however, focuses on PHEV engines that are powered by gasoline because they are the ones currently available in the U.S. market.

PREPUBLICATION DRAFT—Subject to Further Editorial Correction

PEVs are often defined by the number of electric miles that they can drive. A BEV that can drive 100 miles on one battery charge is designated as a BEV100; likewise, a PHEV that can drive 40 miles on one battery charge is designated as a PHEV40.

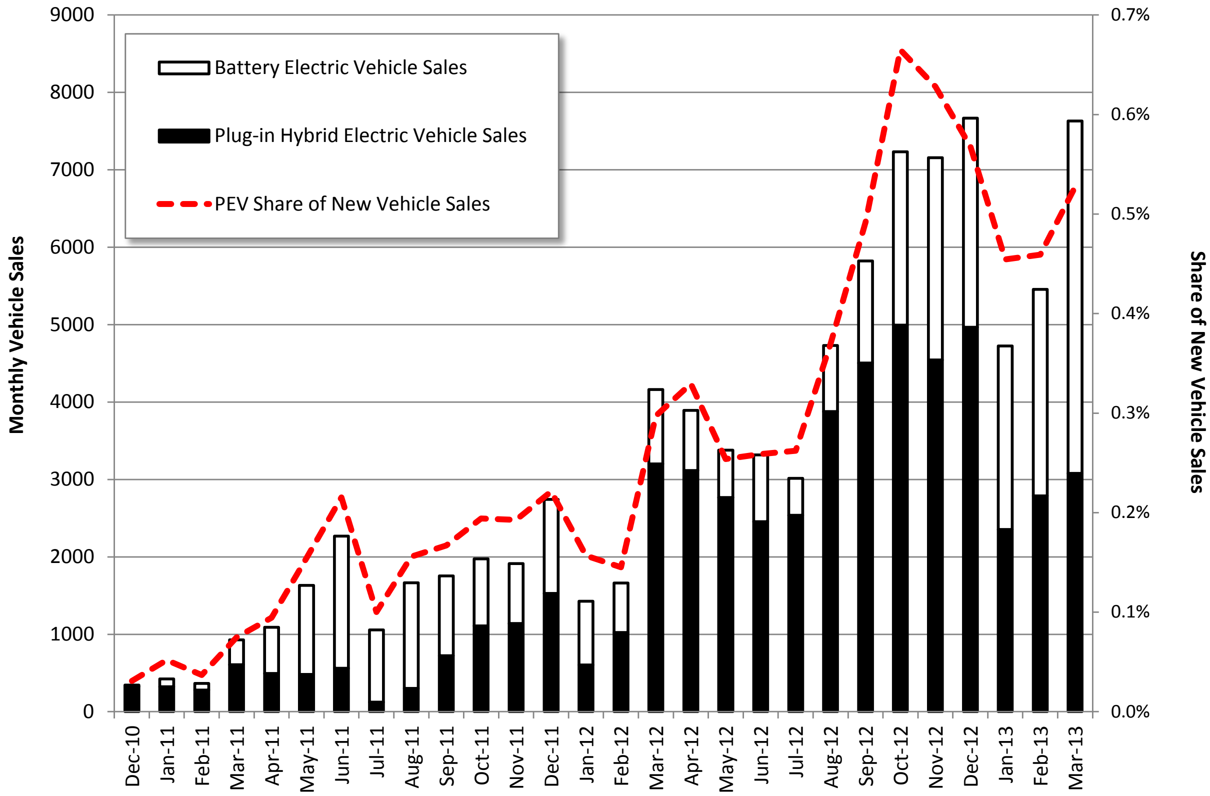

FIGURE 1-1 Plug-in electric vehicle (PEV) sales from December 2010 to March 2013 as monthly sales (left) and as a percentage of all new vehicle sales (right). SOURCE: Data from HybridCars.com, see http://www.hybridcars.com/.

Figure 1-1 shows sales of PEVs since they were introduced into the U.S. market. As of March 2013, almost 90,000 PEVs had been sold. The committee notes that PEV models tend to be introduced initially in a few regions (such as California and Oregon) before being deployed nationally. Although comprehensive demographic data do not appear to be available, some data suggest that PEVs are not yet appealing to the broad market of automobile consumers (Thompson, 2012). Current PEV owners appear to be predominantly well-educated men in an upper income bracket (EVIX, 2012; Thompson, 2012) who were motivated to purchase a PEV primarily by concerns about the environment (40 percent), oil independence (40 percent), and fuel costs (20 percent) (Thompson, 2012).   Some (Heffner et al., 2008; Axsen and Kurani, 2012) have noted that PEV purchasers see the vehicles as status symbols that communicate their concern for the environment and their position as early adopters of leading-edge technology.

To identify and understand the needs of and barriers to PEV deployment, one can consider the PEV ecosystem illustrated in Figure 1-2 as a conceptual model for evaluation. It includes the car manufacturer, which supplies the vehicles to a car dealer, and the customer, who potentially becomes the PEV owner. The customer and the owner are distinguished because they have separate needs, and not all customers will become owners.[5] The PEV must have access to a charger that allows the car to connect to the electric grid and recharge its battery. Typically, a charger is in an owner's garage or next to the driveway so that the battery can be recharged at home after use. Those in single-family or multifamily dwellings that lack access to a garage or driveway might not have convenient access to a charger and therefore to the electricity needed to power the vehicle. There is considerable interest, therefore, in chargers at workplaces and in public spaces, particularly those at which the vehicle will spend at least several hours, such as parking lots for malls, movie theaters, and airports. The chargers and their network are considered the charging infrastructure. The last component of the PEV ecosystem is the electricity system, through which the electricity for charging the vehicle battery is obtained. Those various components are discussed more fully in the later chapters of this report.

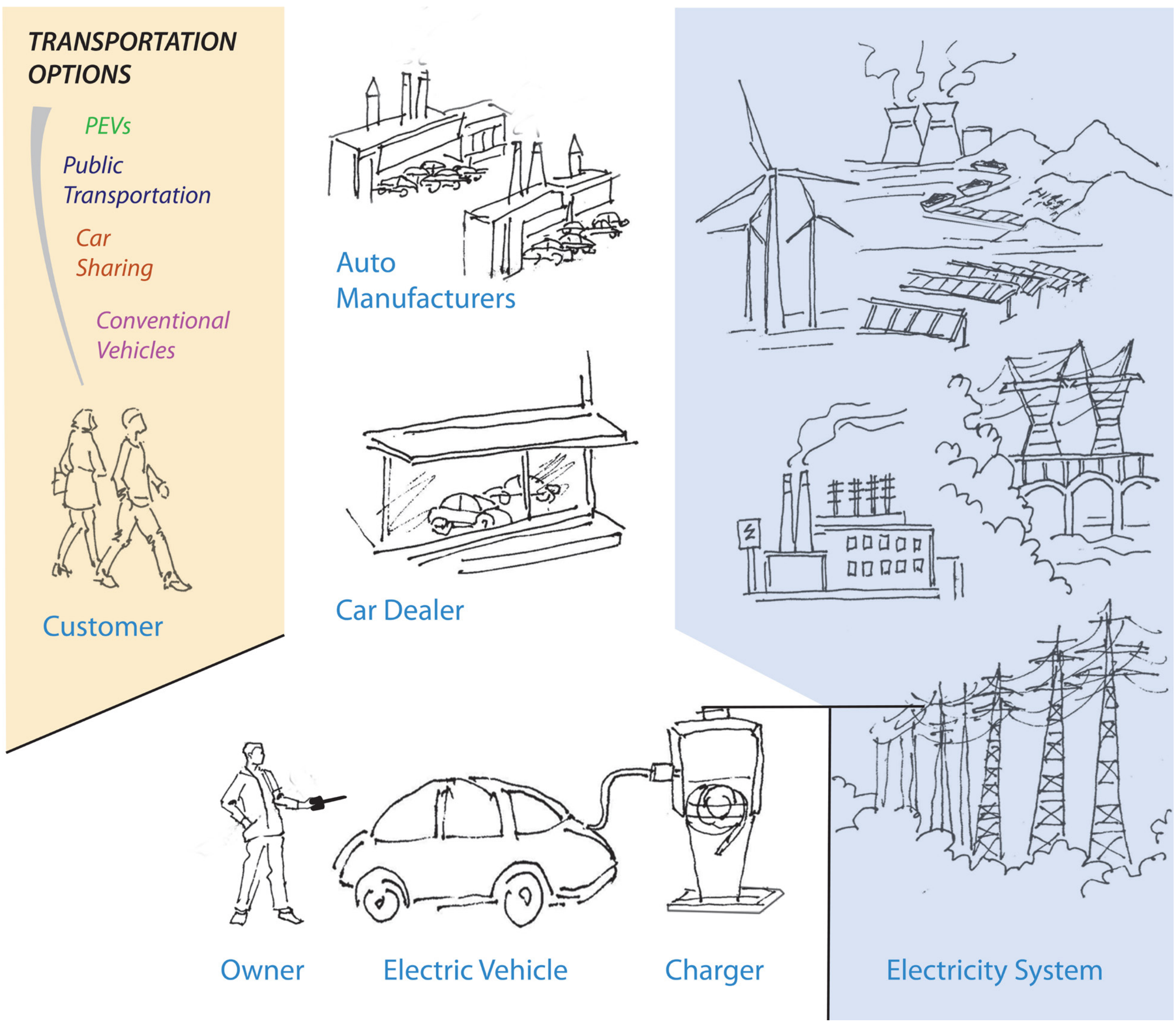

FIGURE 1-2 The ecosystem of the plug-in electric vehicle, which includes the automobile manufacturer, the car dealer, the customer, the owner, the electric vehicle, the charger, and the electricity system.

[5] No distinction is made here between people who own, rent, or lease a vehicle because they will have similar needs—most important, the need to charge the vehicle.

POSSIBLE ADVANTAGES AND DISADVANTAGES OF ADOPTION OF PLUG-IN ELECTRIC VEHICLES

PEVs offer several advantages over conventional vehicles. The most obvious for the owner are lower operating cost, less interior noise and vibration from the power train, often better low-speed acceleration, the ability to fuel up at home, and zero tailpipe emissions when the vehicle operates solely on its battery. BEVs have no conventional transmissions or fuel-injection systems to maintain and no spark plugs to change, and the regenerative braking system greatly prolongs the life of conventional brakes and thus reduces brake repair and replacement costs. On a larger scale, PEVs offer the potential for decreasing U.S. dependence on petroleum imports, increasing U.S. energy security, and creating employment opportunities. Relative to internal-combustion engine vehicles, they have the ability to decrease on a well-to-wheels basis[6] emissions of greenhouse gases (GHGs) and pollutants that affect public health; however, their use could result in a slight increase in emissions of some pollutants (EPRI/NRDC, 2007; Kammen et al., 2009; Elgowainy et al., 2010). The degree to which PEVs affect pollutant emissions will depend on how the electricity that fuels a vehicle is generated, the degree to which charging of the vehicle is managed, and the degree to which emissions from power-generation sources are controlled (Peterson et al., 2011). Given that passenger cars and light-duty trucks—a category that includes sport-utility vehicles, pickups, and minivans—were responsible for about 16 percent of U.S. GHG emissions in 2010 (EPA, 2012), PEV adoption has the potential to reduce GHG emissions substantially as the electric grid shifts from coal plants to power-generation sources with lower life-cycle emissions. PEVs might also act as an enabler for renewable power generation by providing storage through smart-grid applications.

PEVs, however, also have important disadvantages. Current limitations in battery technology result in restricted electric-driving range, high battery cost, long battery-charging time, and uncertain battery life. Concerns about battery safety, depending on the chemistry and energy density of the battery, have also arisen. PEVs have higher upfront costs than their conventional-vehicle counterparts, and there is a need to create a charging infrastructure to support PEVs whether at home, at work, or in a public space. Beyond the technical and economic barriers, people are not familiar with the capabilities of PEVs, are uncertain about their costs and benefits, and have diverse needs that current PEVs might not meet. If the goal is widespread deployment of PEVs, it is critical to identify and evaluate the barriers to their adoption.

One possible disadvantage that has been raised in the context of widespread PEV deployment concerns funding for transportation infrastructure. Motor-fuel taxes generated $70 billion in revenue for federal and state governments in 2010, nearly all of which was dedicated by law to transportation uses (APTA, 2012, Table 56; FHWA, 2012, Tables HF-10, SDF, FE-210). Regardless of PEV purchases, the share of highway funding derived from fuel taxes and other user taxes has been declining as a result of improved fuel economy, political resistance to tax-rate increases, and the 2007-2009 recession. States recognize that new arrangements for transportation finance will be essential in the future, and experimentation with alternative revenue sources for transportation over the next decade appears likely. At least two states (Washington and Virginia) have imposed special registration fees on PEVs (DOE, 2013b) to make up for lost fuel-tax revenue, and such fees might deter PEV purchases, although they are small compared with current subsidies to PEV buyers. The final report of this committee will consider the effect of PEV promotion on fuel-tax revenue and on proposals for reform of transportation-funding arrangements, including proposals of a 2006 committee of the Transportation Research Board of the National Academies (TRB, 2006).

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[6] The term *well-to-wheels* refers to greenhouse-gas emissions from a vehicle's tailpipe (tank-to-wheels) and upstream emissions from the energy source used to power a vehicle (well-to-tank).

THE COMMITTEE AND ITS TASK

The committee includes experts on vehicle technology, utilities, business and financial models, economics, public policy, and consumer behavior and response (see Appendix A for biographic information). As noted above, the committee was asked to identify market barriers that are slowing the purchase of PEVs and hindering the deployment of supporting infrastructure in the United States and to recommend ways to mitigate the barriers. The committee's analysis is to be documented in two reports: an interim report and a final comprehensive report. The present report fulfills the request for the interim report and addresses specifically the following issues: infrastructure needs for electric vehicles, barriers to deploying that infrastructure, and optional roles for the federal government in overcoming the barriers with initial discussion of the pros and cons of the options. This report does not address the committee's full statement of task and does not make any recommendations because the committee is in its initial stages of data-gathering. The committee will continue to gather and review information and to conduct analyses through late spring 2014 and will issue its final report in late summer 2014. To be consistent with NRC policy, the committee has tried to avoid making any premature recommendations that could be contrary to what might emerge in its final report. (See Appendix B for the full statement of task, which describes the complete list of issues that the committee will address in its final report.)

THE COMMITTEE'S APPROACH TO ITS TASK

Three meetings were held to accomplish the task of drafting the interim report. The first two meetings included open sessions during which the committee heard from the sponsor and invited speakers representing automobile manufacturers, electric utilities, charging providers, local governments, and PEV demonstration projects (see Appendix C). On the basis of information received at the meetings, a preliminary literature review, and its own expertise, the committee prepared this interim report.

The committee notes that it accepted its charge and is not debating the merits of promoting, enabling, or increasing PEV adoption. This report focuses on infrastructure and near-term options that can help to extend PEV adoption from first adopters to the next segment of PEV owners who are more risk-averse and require greater reliability. Options that can alleviate barriers in the near term might help to broaden and extend the adoption of PEVs into the mainstream market. Such a focus is consistent with the task statement for this interim report and with the time allotted for its completion.

Battery costs and capability are major factors that hinder PEV deployment. As noted earlier in this chapter, batteries are a focus of vehicle-technology programs of DOE and other laboratories, and continued federal involvement through research and development might help to lower costs and improve battery performance of PEVs. However, the task statement for the interim report focuses solely on barriers related to the deployment of *infrastructure* for PEVs and the possible roles that the federal government could play in mitigating these barriers. In its final report, the committee will consider a broader array of issues facing PEV deployment, including technologic and economic barriers.

ORGANIZATION OF THIS REPORT

This interim report is organized into four chapters and four appendixes. Because the need for infrastructure depends ultimately on PEV sales, Chapter 2 focuses on the barriers to PEV adoption from the customer perspective. Chapter 3 describes various charging options and the infrastructure needed for them. Chapter 4 discusses the electric grid and what might be needed in the future to ensure a stable electricity distribution system. Each chapter discusses possible roles of the federal government and the pros and cons of the various options. Appendix A provides the committee's biographic information, Appendix B provides the statement of task for the full study that will be addressed in the committee's final report, Appendix C lists the meetings and presentations made in open sessions, and Appendix D provides information on technical specifications of PEV charging components.

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2

The Customers, Manufacturers, and Dealers

The customer is identified in Chapter 1 as part of the ecosystem of the plug-in electric vehicle (PEV) and is important to consider in identifying needs for and barriers to the deployment of PEVs and the necessary infrastructure. Potential customers include individuals, households, and organizations—such as rental-car companies, corporations, and government—that purchase fleets of vehicles. In this chapter, the committee focuses on individuals and households because they make up the largest segment of potential buyers and because there might be more obstacles in the way of their adoption of PEVs. The chapter first describes customer needs and barriers to PEV adoption and then proposes possible government roles in overcoming the barriers described. It concludes with a brief discussion of automobile manufacturers and dealerships and the challenges that they face in promoting the adoption of PEVs. Fleets are discussed in Chapter 3.

CUSTOMER NEEDS AND BARRIERS

As noted in Chapter 1, PEV ownership has societal and personal benefits. However, widespread adoption of PEVs will require effective communication with customers on how the vehicles work and how they fit into their lives; vehicles that offer safe, comfortable, and reliable transportation at costs that are competitive with those of conventional vehicles (direct costs of purchasing and total costs of owning and operating the vehicle); vehicles that offer an adequate range of travel; and an infrastructure that provides convenient charging and servicing. Those needs shed light on the most important barriers to customer adoption, as discussed below.

Lack of Customer Knowledge of and Experience with Plug-in Electric Vehicle Technology

Most potential customers have little knowledge of PEVs and almost no experience with them. Surveys indicate that they ask many questions, including, Are these cars powerful enough for freeway driving? Are PEVs safe when going through puddles? How much will PEVs add to my home electricity bill? Are electric vehicles any better for the environment than conventional vehicles? (Kurani et al., 2009; Turrentine et al., 2011). The lack of familiarity is not surprising inasmuch as there are relatively few PEVs on U.S. roads (see Figure 1-1), and these are concentrated in a few regions. Few people even know someone who has practical experience with driving or charging the vehicles. Thus, it is often difficult for people to develop an interest in PEVs, let alone to decide to purchase one, even if it might be a suitable option for their transportation needs. Lack of familiarity with the vehicles and their operation and maintenance creates a substantial barrier to widespread PEV deployment; the following sections highlight a few important areas that need to be addressed.

Electricity as a Fuel

Few people or businesses in the United States have any experience with using electricity as a fuel for their vehicles, so potential customers do not have an intuitive feel for how much it costs to drive a PEV any given distance, how much it will cost per month or per charge session, or how long it will take to charge the battery. They will not be able to estimate easily how much money they might save compared with the costs of a conventional gasoline vehicle over a year, lease period, or expected period of ownership. Consider, for example, the Ford Focus. At a national average cost of electricity of $0.12/kWh, the electric version of the vehicle would cost about $0.04/mile; in contrast, the gasoline-fueled version would cost about $0.12/mile at a national average regular-gasoline price of $3.65/gal. However, such a comparison does not take into account any differences in purchase price, maintenance costs, or costs for a vehicle charger; and electricity and gasoline costs are going to be regionally and temporally dependent. Moreover, if customers are interested in the environmental benefits of their vehicle, they are unlikely to know whether their electric utility (or the utility supplying power at their workplace or at a publicly accessible charging station) generates electricity from a low-carbon source or from renewable energy.

To help customers to understand fuel costs or consumption, the Environmental Protection Agency has recently redesigned its window labels to provide information that will be more relevant to new-car buyers. The labels now include the estimated fuel costs for a year and for PEVs the MPGe (miles per gallon equivalent), which is a measure of the energy efficiency of the vehicle and should help customers to understand electricity as a fuel. However, many of the metrics are not intuitive and are not entirely representative of the costs and benefits that a specific owner might encounter; for example, the plug-in hybrid electric vehicle (PHEV) label is generated on the basis of an assumed fraction of electric miles, and a given owner's fraction of electric miles is likely to vary. On-line calculators that are offered by some Web sites help new-car buyers with such cost-benefit analysis, but taken as a whole, such issues underscore that electricity as a fuel is not as familiar as gasoline.

There are differences between PEVs, specifically PHEVs and battery electric vehicles (BEVs). Depending on the vehicle's energy-use displays, a BEV driver can learn how much it costs to charge a vehicle at home, at work, or at public chargers; how many kilowatt-hours it takes to drive to a desired destination; and how many kilowatt-hours it takes to accelerate. PHEV owners must take more factors into account in projecting their energy costs because the ratio of miles driven on electricity vs gasoline will depend on their driving patterns and on how often they charge their vehicles. Thus, potential customers must consider their own behaviors and vehicle performance to estimate future costs on a monthly basis.

The Vehicle Battery and Charging

Two issues related to the vehicle battery create confusion. First, potential PEV buyers who are familiar with ordinary car batteries and other consumer batteries that have short lifetimes and contain toxic materials might be concerned about the proper recycling or disposal of PEV batteries. However, lithium-ion batteries can be more safely disposed of in landfills than other battery types because they contain smaller quantities of toxic heavy metals. Analyses also have found that lithium-ion batteries are less toxic than alternative batteries over the full life cycle of production, use, and disposal (NHTSA, 2012a, Section 7.2.2). Furthermore, there are concerted efforts to develop reuse-and-disposal programs for the PEV batteries (UC Davis, 2012).

Second, the vehicle requires a charging infrastructure, which can confuse or complicate the vehicle-purchase process. Typically, car buyers are accustomed to a shopping process that includes some Internet research, visits to various local dealerships, and a final vehicle selection at a dealership. The purchase of a conventional vehicle usually can happen quickly with financing and other support possible in a few hours at a dealership. PEVs can add complexity to the process because customers might want to inspect their homes to ensure proper electric capacity before purchasing a vehicle. Each home will be different in costs and complexity. A process that includes inspecting, costing, permitting, and installing can take days or even weeks and add time, multiple cost factors, and uncertainty to the car-buying process. A customer might also want to research workplace-charging and public-charging options, and this would further lengthen and complicate the purchasing decision. (See Chapter 3 for a further discussion of charging and various requirements and costs.)

Driving and Ownership Experience

PEVs provide a driving experience that is different from that of a vehicle that has an internal-combustion engine. Some of the differences are that electric motors have high torque and thus accelerate faster at lower speeds and produce different sounds—for example, less motor noise on acceleration. Furthermore, most PEVs do not have gears, and most use regenerative braking functions, which vary among PEVs in design and intensity.[1] Combined, those driving characteristics can be unexpected, disliked, or enjoyed by drivers.

Owning a PEV will also entail different maintenance and service requirements. A potential customer will typically have little knowledge about exactly what maintenance is required and might have concerns about who can do the necessary maintenance. A need to rely on a dealer for servicing might not be appealing to some who would prefer to use a local mechanic or repair shop. Because of the specialized technical skills required and tool costs (Colias, 2012), local repair shops will most likely lag in obtaining the training and equipment needed to service such vehicles. PEV owners and operators also need to be aware of basic safety practices to avoid risks of electric shock or fire in the installation of home chargers, vehicle charging, and maintenance (ESFI, 2012). The National Highway Traffic Safety Administration has identified safety precautions for vehicle occupants, emergency responders, and towing and repair workers in case a PEV is damaged in a collision or other event (NHTSA, 2012b).

Costs

The direct cost of the vehicles and uncertainty about the total cost of ownership (fuel savings, maintenance costs, and resale value) are barriers to the adoption of PEVs, which have greater initial upfront costs than comparable conventional vehicles. For example, the plug-in Ford Fusion Energi SE has a starting manufacturer suggested retail price (MSRP) of $39,495 compared with a starting MSRP of $24,495 for the conventional 2013 Ford Fusion SE and a starting MSRP of $27,495 for the Ford Fusion Hybrid SE (Ford Motor Company, 2013). There are tax incentives to purchase a PEV, but they offset the cost premium only partially. The committee cautions that such prices are not directly comparable in that there are often differences in interior features and non-power-train technologies between hybrid, plug-in electric, and standard models; furthermore, the MSRP is simply a price point that a manufacturer targets to generate a specific volume of sales and might not be indicative of the real cost of the technology. Such comparisons are, however, illustrative of choices that face a typical consumer. The major contributor to the high upfront costs is the lithium-ion battery; costs are likely to decrease through continued advances in battery technology via research and development and through reductions in manufacturing costs via manufacturers' learning and increased production volume.

For an electric vehicle to be cost-competitive with comparable conventional models, it will need to offer customers substantial fuel savings. Customers who want to estimate their fuel savings need some understanding of electricity costs and what is likely to happen to gasoline prices. Both factors create substantial uncertainty for the customer. Furthermore, because the current generation of PEVs is quite new, it is difficult to estimate the service costs and resale value of the vehicles.

[1] Regenerative braking slows a vehicle rapidly without the use of a brake in single-pedal designs.

Although the magnitude of the effect of fuel price on consumer decisions is uncertain, it is reasonable to expect that a higher gasoline price would promote PEV sales. For example, Li et al. (2008) estimated that a 10 percent increase in gasoline price would generate a 2 percent increase in fleet-fuel economy (in miles per gallon) in the long term, and Busse et al. (2013) estimated that the short-term effect of a $1/gal increase in gasoline price is to decrease the market share of currently available car models in the lowest fuel-economy quartile by 6 percent and increase the market share of cars in the highest fuel-economy quartile by 7 percent. The low price of gasoline in the United States compared with Europe and Japan could be regarded as a barrier to PEV adoption here. The price of gasoline could increase in the future as the result of an increase in the world price of petroleum or as a result of the government's increasing taxes on motor fuels or instituting a broad-based carbon tax.

A large body of research indicates that people heavily discount the value of future gains, and this leads to a strong bias toward current-gain maximization and current-cost minimization (Loewenstein and Thaler, 1989; Frederick et al., 2002; Harris and Laibson, 2002; Hughes et al., 2006; Greene, 2011; Allcott and Wozny, 2012). Thus, for individuals, upfront-cost premiums will typically be difficult to overcome with fuel-savings promises. Business customers, such as those for fleets, are much more likely to analyze the cost and gains to estimate total cost of ownership more accurately.

Vehicle Range

Vehicle range is the most pronounced difference between BEVs and PHEVs. For people who travel primarily short distances or have alternative means of transit for longer trips, the range of BEVs might not pose a concern. For others, however, a small range—or perceptions of a small range or inaccessibility of charging—could be a substantial barrier to the adoption of BEVs. Furthermore, although a driver might not need a vehicle for long-distance travel often, many people see it as advantageous to have the option of such travel. Thus, a vehicle without such capabilities might be valued less by a potential customer because of the loss of utility.

Most current models of BEVs have ranges that are smaller than those of conventional vehicles. For example, the range of the 2012 Nissan Leaf is about 73 miles, and the range of its closest conventional counterpart, the 2012 Nissan Versa, is about 300 miles (fueleconomy.gov, 2013). A notable exception is the Tesla Model S, which can have a range of about 265 miles; it has a current starting price of $72,400 even after a $7,500 federal tax credit, so it is priced out of the range of the average customer (Tesla Motors, Inc., 2013). Thus, most BEV drivers will need to plan their trips carefully and will often not have the option of making a last-minute decision to take an unplanned trip.

As noted, PHEVs are different from BEVs in that they have internal-combustion engines that eliminate the range constraints of being powered only by a battery. However, the restricted range of electric operation of PHEVs might be a dissuading factor for those who drive long distances often because the potential for fuel savings is diminished. Without the promise of substantial fuel savings, PHEVs are considerably less attractive, especially if they are sold at a price premium relative to their conventional-vehicle counterparts.

Whether a vehicle is considered an attractive option by a customer is determined by the value proposition, which considers how well the vehicle meets the customer's needs and how well the vehicle price matches what the customer is willing to pay to satisfy the needs. Because travel patterns, lifestyles, and income levels vary, range is only one component of that value proposition. If someone has access to a second vehicle, the small range of most BEVs might not constitute as substantial a value loss as it will for a household that has only one vehicle. PHEVs have seen a substantial growth in sales over the last year, boosted largely by an increase in the numbers of vehicle and range options available (see Figure 1-1), but BEVs have also seen their shares rise relative to conventional vehicles. Because the market is still evolving, it is difficult to anticipate whether particular vehicle types or battery ranges will emerge as having the best value for customers. As conventional vehicles become more efficient and vehicles powered by other alternative fuels (such as natural gas and hydrogen) appear in the marketplace, the value proposition will continue to change.

The committee notes that commuting fueled by electricity stored in vehicles is feasible on a large scale in the United States, at least in principle. Figure 2-1 shows the distribution of daily travel distance for vehicles. According to the 2009 National Highway Transportation Survey; 68 percent of all vehicles traveled less than 40 miles on a given day, and 92 percent of all vehicles traveled less than 73 miles (FHWA, 2011). Although the survey provides a snapshot of all vehicles on the road, it does not indicate the day-to-day variability for a particular vehicle, which is crucial for understanding the applicability of a particular BEV or PHEV for an individual household (Lin et al., 2012; Traut et al., 2012; Tamor et al., 2013).

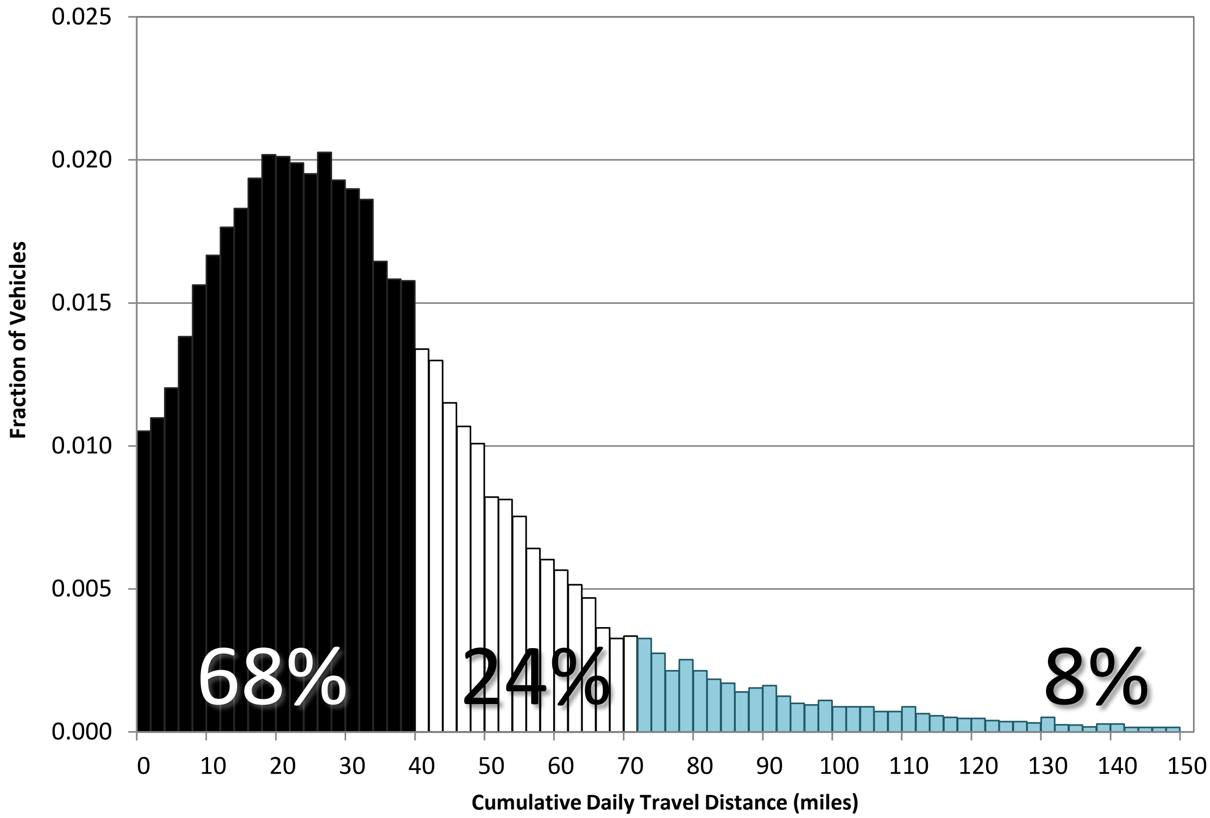

FIGURE 2-1 Distribution of daily travel distance (FHWA, 2011). Colored ranges are marked at 40 and 73 miles.

Access to Charging

For people in single-family homes that have carports or garages, residential charging *should not* pose a problem other than the cost and logistics of installing a charger. An exception might be those who rent their homes and, therefore, would not have authority to make structural changes in the property. For the roughly one-third of households that do not have access to a carport or garage (U.S. Census Bureau, 2012), residential charging is problematic. Although many of those households will have access to a common parking garage or lot, they generally will not have authority to make structural changes; even if they do, the costs involved might be prohibitive. For households that do not have access to a carport or garage and have only an option of street parking, the ability to access charging overnight is extremely problematic. (Charging options are further discussed in Chapter 3.)

OPTIONAL ROLES OF THE FEDERAL GOVERNMENT IN ADDRESSING CUSTOMER NEEDS AND BARRIERS

The federal government has several possible roles in educating customers, providing incentives, and supporting research on customer behavior and on the effectiveness of policies. Some might argue that the federal government should play a major role in the adoption of PEVs. Although a person might derive personal benefits from PEV ownership, society has the potential to benefit from PEV adoption in, for example, improvements in local air quality, reductions in greenhouse-gas emissions, decreased dependence on petroleum, and greater energy and economic security. Expecting individual customers to bear the brunt of the costs of societal benefits might not be realistic or feasible.

Customer Education

Customers have many questions about PEV technology and, in many cases, substantial misperceptions. They need information on vehicle costs and performance, operating and maintenance costs, incentives available, and charging infrastructure required. The federal government could consider providing the following:

- Public-service announcements that use various communication media—traditional and social media—to showcase current PEV owners, illustrate how a PEV meets various transportation needs, provide information or links to Web sites (such as fueleconomy.gov) that help customers to understand purchase and operating costs and available incentives, and describe the societal benefits of PEV ownership, such as reductions in petroleum use and greenhouse-gas emissions.
- Ride-and-drive activities or demonstrations at high-visibility locations—such as football stadiums, large office parks, and retail locations—because evidence suggests that people are more likely to be interested in purchasing PEVs if they have driven them (Kurani et al., 2009; Turrentine et al., 2011), and people often do not want to go to a dealer to see the vehicles. Department of Energy (DOE) programs—such as the Clean Cities program, which is a coalition of stakeholders that seek to encourage alternative transportation solutions in U.S. communities and often works with local dealerships—could be used for those types of demonstration activities to facilitate customer education outside the dealership environment.
- Marketing targeted to audiences that have transportation needs that might fit PEVs, such as commuters in suburban areas who drive regularly to public transportation stations a short distance from home. Those audiences would most likely not need a public charging infrastructure if they have residential charging because they are not likely to travel more than 20 miles to commuter parking lots.
- Curriculum so that educators can design instructional units on PEVs that might also include demonstration activities as part of science education.

Customer-education activities would increase the public’s familiarity with a relatively unfamiliar technology. Some might then develop an interest in purchasing PEVs, especially once they learn more about various federal, state, and local government incentives. In contrast, the activities would come at a cost, and the efforts would have to be sustained over a relatively long period and be directed at people who are likely to be in the market for PEVs. An improved understanding of customer perceptions, interests, and behavior would be needed to develop targeted marketing campaigns.

Customer Incentives

Federal, state, and local governments can offer (or continue to offer) many incentives to encourage potential customers to buy and use PEVs, and the federal government could use its convening power to facilitate coordination of various state and local incentive programs. Incentives that can spur purchases include (1) purchase rebates, income tax credits, or sales-tax reductions or exemptions; (2) subsidies that streamline the permitting process for installing chargers; (3) access to high-occupancy vehicle or carpool lanes; (4) free parking, reduced costs for parking, or greater access to parking; (4) reduced or exempted license or registration fees; and (5) taxes on fuels.

Financial customer incentives can offset the uncertainty of costs faced by potential customers, and such assistance will be important in second-generation markets, in which buyers are less adventurous than early market adopters. Research on the effectiveness of past and existing customer incentives to purchasing alternative-fueled vehicles would help to inform the design, cost effectiveness, and creation of new incentives. For example, studies involving hybrid-electric vehicles, such as the Toyota Prius, have suggested that customers respond better to immediate incentives, so using purchase rebates instead of income-tax credits is likely to be much more effective (Gallagher and Muehlegger, 2011). Because some incentives cost the government considerably more than others, it is important to understand their effectiveness.

Research on Customer Perceptions, Attitudes, and Behavior

Few data on customer perceptions, attitudes, and behavior regarding PEVs are publicly available. Some studies have examined those issues (Axsen and Kurani, 2012; Heffner et al., 2005), but further research could help to determine how to structure programs or policies to maximize investment in PEV adoption. The federal government could support research to learn why potential customers would or would not purchase PEVs and how they respond to government incentives. It could also support research on regional differences—in housing stock, experience with and exposure to technology, electricity prices, availability of alternative transportation options, and customer attitudes—to see how the differences influence purchases of PEVs.

The government could require all those who receive government funds to report and share data anonymously about customer adoption and acceptance of and behavior concerning PEVs. That would include charging-service providers, automobile manufacturers, participants in demonstration projects and smart-grid programs, and customers who use tax credits. The government would need to provide the data in a usable format to the public, companies, and scientists to enable research and take privacy issues into account.

Research on Policy Effectiveness

Little research has been done on the effectiveness of government policies with respect to PEVs to determine which are the most successful and why. Specifically, there has been little research to determine which government incentives are most influential in affecting customer decisions, which public-education efforts work, and which kinds of demonstration activities are most helpful. To ensure that investment in PEV adoption is maximized, the federal government could support research on policy effectiveness.

Because the development of new automotive technology is a slow deliberative process that goes through many stages, an adaptive-management approach is crucial for the development of effective policies. The development of the PEV industry is even more complex and dynamic than the development of the original hybrid vehicles, which after a decade have achieved a 17 percent market share in Japan (JAMA, 2012a,b) and a 7 percent market share in California (Edmunds.com, 2012), although the market share in the entire United States remains at just above 3 percent. Those market shares were partly achieved using an array of tax and other incentives. As battery costs are reduced, new vehicle systems are launched, and charging infrastructure is installed, PEV manufacturing and markets will need to go through at least three stages of vehicle and market-segment development—from first-generation vehicles and early market adopters (about 1 to 3 percent of the U.S. market) to second-generation vehicles and "fast followers" (about 2 to 5 percent of U.S. market) and finally to third-generation vehicles and the early majority segment (about 3 to 10 percent of the U.S. market)—if a sustainable industry is to be achieved. An adaptive-management approach to policy development is critical during these early stages of market adoption. That is, there need to be careful monitoring and continuing measurement of the effects of incentives, technology rollout, and infrastructure design, and the resulting information needs to be used to adapt or change policies and other efforts to make them more effective in achieving widespread PEV adoption.

THE AUTOMOBILE MANUFACTURER

Automobile manufacturers face many technical challenges in developing and marketing PEVs, and these will be discussed in the committee's final report. The focus here is on the customer, and the major barriers are the few choices in PEV models offered by automobile manufacturers—mostly compact sedans or subcompact vehicles—and the small number of automobile manufacturers that are offering any choice.[2] Although automobile manufacturers will probably be supplying more choices in electric-drive technology in the near future, the few models now offered do not meet the needs of all customers, especially given that 52.2 percent of the passenger-vehicle market in 2012 in the United States is comprised of light-duty trucks—a category that includes pickups, sport-utility vehicles (SUVs), and minivans (WSJ, 2013). The development of new PEV platforms will require substantial investment, and sales of PEVs must increase to justify that investment. Furthermore, development of PEV light-duty pickup trucks and SUVs presents additional cost and technical challenges because of the capacity, weight, and volume of the batteries required for adequate performance (Cheng et al., 2009). However, some industry experts view electric-drive initiatives by automobile manufacturers as strategic investments because they present an opportunity to develop a standardized drive train that can be used for multiple platforms and thus save on manufacturing and labor costs. If PEV sales increase substantially, automobile manufacturers will be more willing to extend the electric-drive technology to other platforms, and this will lead to greater customer choices in vehicle models.

One caveat to that scenario is that electric-drive technology needs to evolve, mature, and become economically producible on a large scale before automobile manufacturers can offer more variety. The federal government has supported basic research on and development of electric-drive technologies, particularly battery development, and continued federal support should help to reduce technology costs and indirectly encourage the use of electric-drive technology in a variety of vehicle models. Other policy options available to the federal government could spur greater development of PEVs by automobile manufacturers, such as raising fuel-economy standards, instituting zero-emission-vehicle mandates, and creating carbon taxes. However, evaluation of those broad-scale options is beyond the committee's charge for this interim report.

DEALERSHIPS AND RETAIL OUTLETS

Dealerships are the primary sales and distribution channel for vehicles, so they are the primary interface with customers. This section addresses various aspects of dealerships that create potential barriers for encouraging sales of PEVs.

[2] See http://www.hybridcars.com/.

Challenges to Supporting Adoption of Plug-in Electric Vehicles

With few exceptions,[3] dealerships are independent franchises that are not owned or operated by automobile manufacturers. Dealerships are governed and protected by state franchise laws that effectively regulate same-brand competition within their market territory. However, secondary delivery channels—which include car-buying services, major membership organizations (such as the Automobile Association of America), and retailers (such as Costco)—and direct Internet sales have all become competitive forces and have compressed profit margins for dealers on new car sales (Zettelmeyer et al., 2006).

As a result of those trends, dealerships depend more on their other services to generate profits. Their service and parts departments and their financing and insurance and warranty sales are the most important sources for dealer profit. For example, a recent examination of revenue sources and profits at Penske Automotive dealerships, which has operations in the United States and the United Kingdom, showed that service and parts accounted for 13 percent of annual revenues, but 44 percent of gross profits (Henry, 2012).

Those business factors are important for understanding a dealership's motivation to sell and support PEVs particularly when the disincentives are considered. Although it is too early to make definitive statements, some data indicate that maintenance costs will be lower, provided that battery replacement is not required before the end of a vehicle's life. A recent study by the Institute of Automobile Economics (Loveday, 2012) found that maintenance costs of PEVs are estimated to be 35 percent lower than those of comparable gasoline-powered and diesel-powered vehicles. The difference is attributed largely to PEVs' having fewer mechanical and moving parts and reduced brake wear as a result of regenerative braking, having electric motors instead of drive trains with clutches and gearboxes, and having no engine exhaust and emissions systems to repair or replace. Furthermore, PEVs do not require regular trips to the dealership for oil changes, which offer prime opportunities for dealers to examine cars for other potential maintenance and repair items.

Another disincentive for dealerships to support PEVs is that training and educating personnel—salespersons, mechanics, finance specialists, and managers—are expensive for a franchise. New and potentially confusing technologies require extensive education and training not only about a vehicle itself but about the charging infrastructure, tax benefits and incentives, and warranty terms that are unique to PEVs, such as those concerning the batteries. A recent survey of dealerships (McCutcheon-Schour et al., 2012) indicated that current outlets are not fully prepared to explain and educate customers on PEVs and the charging infrastructure required. Given the comparatively high cost of training and preparing dealership personnel and the comparatively greater needs for customer education on PEVs before they are comfortable in making their purchases, there appears to be a critical information gap at the primary point of sale.

Although customers today have unprecedented access to information about vehicles on the World Wide Web, it is questionable whether the available information on the supporting charging infrastructure for PEVs is adequate. Early evidence suggests that customers are *not* adequately informed about PEV charging requirements before they visit dealerships (McCutcheon-Schour et al., 2012), and this again puts the burden of educating them onto the sales staff. The lack of customer education about PEV charging requirements clearly is a barrier that affects customer preparedness and consumes dealership resources. Because the sales staff is focused on sales volume, the additional time that must be spent in educating customers to encourage them to buy PEVs is a disincentive for selling the vehicles.

[3] Tesla, for example, owns showrooms that act as brick-and-mortar points of sale for its cars.

Overcoming Barriers at the Dealership

Research is needed on how to align the needs of dealers with the stated goal of increasing PEV sales. One option is to provide dealer incentives for selling PEV products, and one automobile manufacturer has noted such incentives (Colias, 2012). However, a major barrier is the time required to educate customers. Automobile manufacturers, dealerships, and other industry stakeholders could be doing much more to provide test-drive events as customer outreach and educational opportunities. However, because staffing and providing vehicles for such events consume dealership resources, consideration should be given to how to offset the dealer costs or how to provide the opportunities in a manner that does not require dealership resources. As discussed above, the federal government could support demonstration activities through existing federal initiatives, such as the DOE Clean Cities program.

If one considered only the goal of increasing PEV adoption, there might be other models of closing the knowledge gap between customers and the PEV technology at the point of sale. Some automobile manufacturers have opted to allow vehicle purchase directly from them. The Toyota Prius was initially purchased directly from the manufacturer rather than through franchise dealerships. When the Nissan Leaf was introduced, it could be purchased only through Internet sales. There might be value in considering alternate sales channels, particularly if they can be used to educate customers more directly about the technology, vehicle requirements, and charging-infrastructure needs. More information is needed about the desirability, opportunities, and drawbacks of alternative sales channels because state franchise laws might impede or act as barriers to alternative delivery channels.

By partnering with local utilities, local dealerships might be able to develop a stronger expertise in charging needs at reduced expense. It is in a utility's interest to determine where PEVs will reside to ensure that distribution capacity is adequate (discussed in further detail in Chapter 4), and some local utilities (such as Portland General Electric, Pacific Gas and Electric, and Southern California Edison) are beginning to develop checklists and guidelines for customers who are considering purchase of PEVs that provide information on power requirements, rate options, and vehicles. By providing such guides to dealerships at the point of sale, utilities might be able to obtain advance notice of PEV load, and dealerships might then reduce some of the burden of the education process.

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3

The Charging Infrastructure

One of the critical elements of a plug-in electric vehicle (PEV) is the charging infrastructure. It is a source of confusion for customers (as noted in Chapter 2) and a substantial requirement for enabling the widespread deployment of PEVs. This chapter begins with a basic discussion of charging and then describes possible charging locations and the needs or barriers associated with each. Next, it discusses the charging-infrastructure considerations for fleets and shared vehicles, and it concludes with findings and possible roles for the federal government in overcoming the barriers identified.

In trying to answer questions concerning charging-infrastructure needs, the committee assumed that the goal was to maximize the fraction of miles traveled by light-duty vehicles fueled by electricity. The committee recognizes that the goal influences the type, number, and location of charging infrastructure needed and that other potential goals—such as maximizing the number of PEVs on the road or maximizing the number of miles traveled by battery electric vehicles (BEVs)—might lead to different conclusions. It must be remembered that the committee's stated goal means that it is indifferent to whether miles are traveled by BEVs or plug-in hybrid electric vehicles (PHEVs). The goal of maximizing the fraction of electric miles addresses two objectives of U.S. energy policy noted in Chapter 1: increasing energy security by reducing dependence on petroleum imports and reducing greenhouse-gas emissions. The latter objective will be reached fully only when emissions from the sources that generate electricity for distribution over the electric grid are reduced (this issue is discussed further in Chapter 4).

CHARGING AND HOW IT WORKS

Electricity from a battery powers the electric motor of a PEV in a way that is similar to how gasoline in a tank powers the engine of a conventional vehicle. The range, in miles, of a conventional vehicle depends on how many gallons of liquid fuel the fuel tank can hold and the fuel economy of the vehicle. Similarly, the electric range of a PEV depends on how much electric energy—expressed in kilowatt-hours—the battery can hold. Table 3-1 provides some examples of currently available PEVs, their nominal and usable battery capacities,[1] and estimated electric ranges based on the Environmental Protection Agency (EPA) Federal Test Procedure.

It is important to note that the actual electric range of a vehicle depends on such factors as the weight and age of the vehicle, how aggressively the vehicle is driven, the ambient temperature, the road grade, and the level of air conditioning and heating used. As noted, the estimated electric ranges provided in Table 3-1 are based on the EPA Federal Test Procedure, but other driving cycles, such as the New European Driving Cycle, produce different results. For example, the 2012 Nissan Leaf has an estimated

[1]The usable capacity of a battery is the portion of the total capacity that is accessed by the vehicle during operation. A rechargeable battery, such as those in PEVs, theoretically can be charged to 100 percent of its nominal capacity and discharged to 0%. But allowing the battery to charge and discharge fully could seriously reduce its future performance. Thus, a battery could be limited in its charging range, for example, from 80% to 30% of its capacity. That example represents a 50% state-of-charge range, and the usable capacity of the battery would be 50% of its nominal capacity (NRC, 2010).

all-electric range of 73 miles on the basis of the EPA Federal Test Procedure, but an estimated all-electric range of 109 miles on the basis of the New European Driving Cycle (Crowe, 2013).

TABLE 3-1 Battery Capacities and All-Electric Ranges for Several Plug-in Electric Vehicles

Vehicle	Type	Battery Capacity[a]	Electric Range[b]
2013 Toyota Plug-in Prius 	Plug-in hybrid electric vehicle	4.4 kWh nominal (~3.2 kWh usable)	11 miles (blended) 6 miles (battery only)
2013 Ford C-MAX Energi 	Plug-in hybrid electric vehicle	7.6 kWh nominal (~7 kWh usable)	21 miles
2013 Chevrolet Volt 	Plug-in hybrid electric vehicle	16.5 kWh nominal (~11 kWh usable)	38 miles
2012 Nissan Leaf 	Battery electric vehicle	24 kWh nominal (~21 kWh usable)	73 miles
2013 Tesla Model S 	Battery electric vehicle	85 kWh nominal	265 miles

[a] Nominal battery capacities are reported by manufacturers in product specifications. Usable battery capacities reflect the amount of the nominal capacity that is used during vehicle operation, and the values reported here reflect the actual charge used by the battery to achieve the measured all-electric range.
[b] The electric ranges noted are average values estimated by EPA. Because of the motor size and design architecture of the Toyota plug-in Prius, it requires use of its internal-combustion engine to complete the Federal Test Procedure; therefore, its range is given in blended, charge-depleting operation and battery-only operation. All other vehicle ranges are given only for fully electric, charge-depleting operation.
SOURCES: Based on data from Duoba (2012), DOE (2012, 2013a), and EPA (2012, 2013).

Charging a PEV is analogous to filling a conventional vehicle's fuel tank with gasoline. A gasoline-powered vehicle is attached to a pump that allows the gasoline to flow through a hose into the fuel tank. A typical flow rate of 8 gal/min, for example, means that empty gasoline tanks with capacities of 10 to 20 gal will be filled in a few minutes. Similarly, a PEV is plugged into the electric grid so that electricity can flow through wires and into the battery. An energy flow rate of 6.6 kW, for example, can fill an empty battery with a capacity of 24 kWh in about 4 hours.

The peak charging rate for residential charging is limited by the size of the charger in the vehicle that changes the alternating-current (ac) electricity into direct-current (dc) electricity. A fully discharged battery initially charges at the maximum rate that the on-board charger can manage and then charges more slowly as the battery nears capacity. Thus, a vehicle battery does not charge at a constant rate, and that is why it takes about 4 hours to fill a 24-kWh battery at 6.6 kW. For DC fast charging (discussed below), the component that changes ac to dc is outside the car and is governed by control signals from the car. Regulating the charging rate is necessary to ensure safety and to protect battery life. Although increasing the charging rate with high-power chargers shortens the time needed to charge a vehicle's battery, an important technical issue now being researched is the extent to which faster charging at high power hastens the normal aging of a battery (Francfort, 2013).

The electric "pressure" with which an electric circuit in a home or business can force electricity through wires into some device is measured in volts. The amount of electricity flowing through various devices, the electric current, is measured in amperes. The product of the two is the power flow in watts. Every circuit delivering electricity has a circuit breaker or fuse that keeps the flow of electricity from exceeding the amperes that the circuit can safely provide. For example, a 2013 Nissan Leaf is capable of using a maximum of 30 A of electric current when it is connected to a 240-V electric circuit, so the power flow is 7.2 kW. The car will not accept more current or power even if the circuit is able to provide it. The circuit breaker that monitors the current flow in a dedicated circuit would typically switch off the electricity going to the car if current were flowing at about 40 A because this would indicate a problem with the car. The electric circuit required to do this charging is called 40-A service at 240 V.

As recommended by the National Electrical Code (NEC), an apparatus known as the electric vehicle supply equipment (EVSE) is always connected between the charging circuit and the car to protect the people and the car during charging. The purpose of the EVSE is to create two-way communication between vehicle and charger before and during charging to detect any anomalies that might affect safety or the equipment (Rawson and Kateley, 1998). The NEC (2008) defines the EVSE as "the conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatus installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle" (Section 625.2). Its ground fault interrupters—similar to those used in bathrooms and kitchens—are safety devices that can detect when a small electric current from the circuit has "gone missing" and disconnect the electric circuit and the current flow before anyone is injured. Furthermore, the EVSE is able to communicate with a car to ensure that no current is provided before the car is connected and to ensure that a current larger than the car can handle is not provided. The EVSE for slow charging via 120 V is typically a portable device that can be carried in the car for possible use at remote locations (see Figure 3-1a). The EVSE for normal 240-V charging is typically mounted on a garage wall (see Figure 3-2a) or on a purpose-built column. Fast chargers that use higher voltages have the EVSE built into the substantial charger that is required.

A plug wired to the EVSE connects to a socket on the vehicle. In the United States, there is one standard plug that is used to charge vehicles from the normal 120-V and 240-V circuits found in residences, the J1772 standard set by SAE International (formerly the Society of Automotive Engineers International; SAE, 2012). This interchangeability removes what otherwise could be a substantial barrier to the adoption of PEVs. However, at least two standard plugs are used for the DC fast charging that is becoming available in public locations. Most BEVs on the road that can be connected to a DC fast-charging unit (and the vast majority of chargers that have been installed in the United States, Japan, and Europe) use the CHAdeMO standard. Automobile manufacturers and SAE International have agreed on a new standard that they call the Universal EV Combined Charging System. Furthermore, Tesla vehicles that are now available use a proprietary plug. The lack of component compatibility will effectively reduce the coverage of charging stations by reducing the potential user base or will increase installation costs by requiring charging outlets to be compatible with multiple plug designs. More details on the standards and photographs of the various plugs are provided in Appendix D.

CHARGING LEVELS

As shown in Appendix D (Figure D-5), SAE International defines four levels of charging: slow charging with 120-V ac circuits that is defined by SAE as AC Level 1 charging, normal charging with 240-V ac circuits that is defined by SAE as AC Level 2 charging, and two levels of DC fast charging (DC Level 1 and DC Level 2), which are distinguished by SAE International by the maximum power draw. For the present report, the committee uses the terms *AC Level 1*, *AC Level 2*, and *DC fast charging* to describe the levels of charging available and does not distinguish between DC Level 1 and DC Level 2. The following sections describe those options in more detail.

AC Level 1 Charging

Most electric devices in the United States—such as lamps, small air conditioners, and computers—are plugged into 120-V electric circuits. Wall sockets in essentially every room of every building provide access to 120-V electricity. To prevent fires and other damage to the electric circuits, circuit breakers or fuses incorporated into the electric system typically switch off the electricity if the current flowing through the circuit exceeds 15 to 20 A.

Because the United States has little charging infrastructure dedicated to PEVs, it is important that owners be able to charge their vehicles by plugging into an ordinary 120-V wall receptacle when no better charging option is available. Accordingly, all PEVs can be charged by plugging into 120-V circuits (see Figure 3-1a) and are designed to draw a current compatible with the circuit rating to avoid having a normal circuit breaker turn off the current. That option is essentially a no-cost solution to charging infrastructure. Each hour of charging provides about 4 to 5 miles, depending on the vehicle (see Figure 3-1b). Much like an air conditioner plugged into a 120-V circuit, a charging vehicle typically must be the only device drawing current from the circuit to avoid exceeding the maximum current that the circuit can provide. The PEVs shown in Table 3-1 can easily carry the EVSE needed for AC Level 1 charging. However, the components are not mounted directly on the vehicle and are thus susceptible to theft or vandalism.

The time required for charging a battery that has fully depleted its usable energy (or charge) by using 120 V can be 10 hours or more for PEVs that have a large electric range (see Figure 3-1c). Thus, AC Level 1 charging is not a practical primary charging method for BEVs that use electricity to travel a substantial number of miles. AC Level 1 charging might be useful in some cases to extend the range by a few miles (see Figure 3-1b).

AC Level 2 Charging

The manufacturers' recommended charging for vehicles that have appreciable electric ranges uses 240-V circuits, which can often charge a PEV at least twice as fast as a 120-V circuit. Most residences and businesses have 240-V circuits installed, although the higher-voltage circuits are typically available only at the location of large appliances. Electric clothes dryers, electric stoves and ovens, large microwave ovens, and large window air conditioners typically use 240-V circuits.

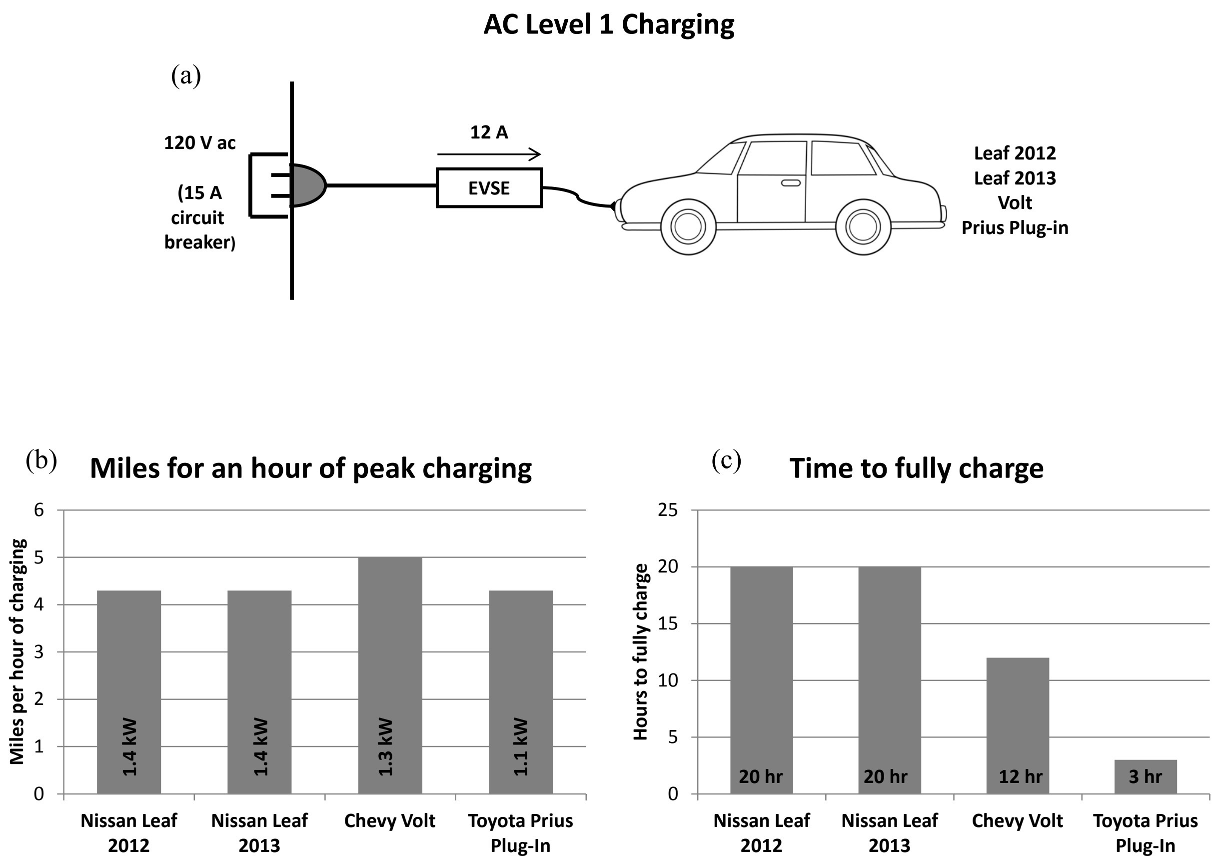

FIGURE 3-1 AC Level 1 charging information. (a) For AC Level 1, a vehicle is plugged into a common 120-V electric socket through a portable safety device labeled EVSE. (b) The mileage range that results from 1 hour of peak charging is about the same for all the example vehicles noted because they are about the same size and weight. (c) Vehicles that have larger batteries to allow them to be electrically powered for longer distances take longer to charge fully. SOURCES: GM-Volt, 2013; Toyota, 2013.

Where there is access to a 240-V circuit, the infrastructure needed (see Figure 3-2a) is much like that needed for AC Level 1 charging (see Figure 3-1a) except that the EVSE is typically mounted more permanently. The 240-V EVSE is connected to the same standard socket that is used on all vehicles for 120-V charging, the J1772 standard, and this makes it possible for different types of vehicles to share chargers.

The number of miles that can be traveled after 1 hour of AC Level 2 charging depends on the vehicle and the electric current (see Figure 3-2b). The important advantage of 240-V charging is that the time required to charge a battery fully is short enough to charge PEVs with substantial electric ranges during the time that a vehicle is parked at a residence or a workplace (see Figure 3-2c). The configuration shown in Figure 3-2 is the one typically recommended for most residences and workplaces.

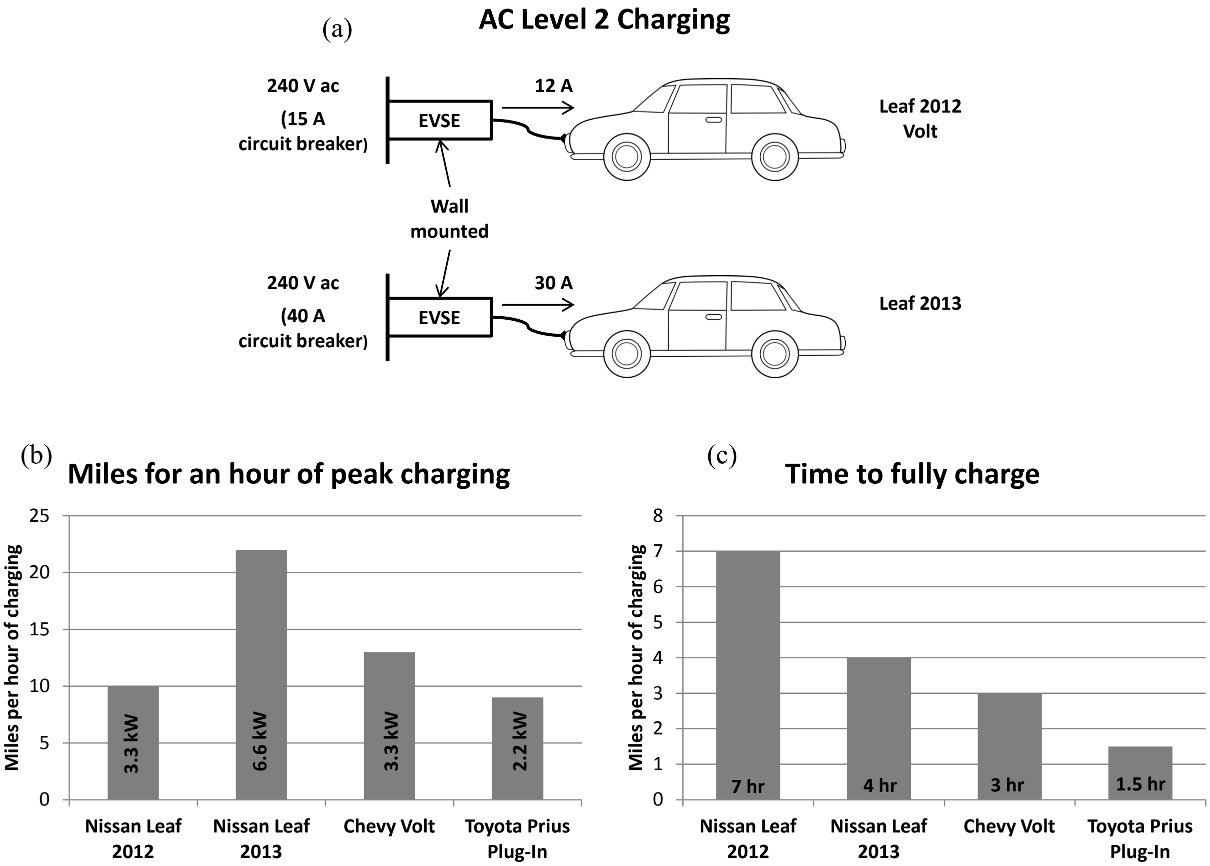

FIGURE 3-2 AC Level 2 charging information. (a) For AC Level 2 charging, a vehicle is plugged into a 240-V electric circuit like those used by electric dryers, stoves, and large air conditioners through a wall-mounted safety device labeled EVSE. (b) The mileage range that results from 1 hour of peak charging depends on how much current the PEV can draw. (c) Vehicles that have larger batteries and ranges take longer to charge fully. SOURCES: GM-Volt, 2013; Toyota, 2013; Voelcker, 2013.

DC Fast Charging

Some PEVs can be charged by using high-voltage (for example, 480-V) circuits that allow the battery to charge much more rapidly. Unlike the charging systems discussed above, the conversion of the ac electricity that is available from the U.S. electric grid to the dc electricity needed to charge the battery takes place in the EVSE rather than in the vehicle. The DC fast chargers typically require a connection to high-voltage, three-phase power that is almost never available in residences or workplaces except where industrial equipment is powered with electricity. Thus, access to the high-voltage electricity is one factor to consider when locating DC fast-charging stations.

Fast charging typically charges a battery to about 80 percent of its usable capacity (see Figure 3-3); charging beyond that point typically cannot be nearly as fast without endangering the battery. In fact, fast charging can shorten the life of a battery because of materials degradation from internal heating. How much the battery life is shortened is being investigated for a Nissan Leaf in a study commissioned by the Department of Energy (DOE; Francfort, 2013).

Permission pending

FIGURE 3-3 DC fast charging a Nissan Leaf. DC fast charging is able to charge a Nissan Leaf battery to 80 percent capacity in less than 30 min. The charge would typically allow a 2013 Leaf to travel about 64 miles.

DC fast charging is not available for most PHEVs, such as the Chevy Volt and the Toyota Prius plug-in, because these vehicles can rely on their internal-combustion engines for longer trips. It is primarily for BEVs, such as the Nissan Leaf and the Tesla Model S. Most PEV models that can accept DC fast charging use the CHAdeMO plug, as do most of the fast chargers installed in the United States, Japan, and Europe. As noted earlier, SAE International has adopted an alternate DC fast-charging standard (the Universal EV Combined Charging System), and many automakers are planning to deliver vehicles compatible with that standard. Tesla has its own DC fast charger and proprietary plug configuration.

Wireless Charging

In its final report, the committee will consider the possibility of charging a PEV wirelessly. Instead of sending electricity through a cord plugged into a vehicle, the energy in wireless charging is transferred inductively from a coil attached to an electricity source to a coil attached to the vehicle; both coils are encased and out of sight below the vehicle. Although that technology is not yet widely available to consumers, wireless charging systems are in the early stages of production and availability, and new designs are being investigated (Electric Vehicle News, 2011; Plugless Power, 2013). The reduced efficiency and increased cost of wireless chargers are disadvantages, especially considering that little time is required to plug in a PEV. However, the advantages of increased convenience and reduced susceptibility to vandalism might eventually be more compelling.

CHARGING LOCATIONS: NEEDS, BARRIERS, AND OPTIONS

This section discusses the similarities and differences between the infrastructure needs of and barriers to residential, workplace, and publicly accessible charging and offers some options for overcoming the barriers. Most electric-charging infrastructure is (and is likely to remain) at residences, where PEVs are available for charging for the longest time. Because PEVs are also parked at workplaces for substantial times on each workday, workplace charging is a promising option where practical ways can be found to provide the needed infrastructure. PEVs typically have much less time available for charging while parked in public places, but charging in publicly accessible locations would serve the needs of PEV drivers if a DC fast charger were available, if the vehicle were parked for at least 4 hours, or if only a partial battery charge were needed.

Figure 3-4 is a representation that PEV manufacturers and other stakeholders often use to contrast the relative importance of PEV charging at residences (most important), at workplaces (important), and in publicly accessible locations (somewhat important) (Karner, 2012; Kjaer, 2012). Figure 3-5 gives a more detailed breakdown of where vehicles are during the day and shows that vehicles spend most of the day parked at home and a substantial fraction of time during the week parked at work.

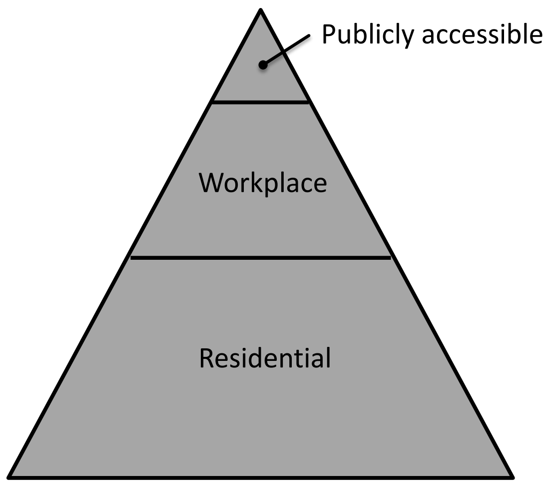

FIGURE 3-4 The charging pyramid represents the relative importance of residential, workplace, and publicly accessible charging. It indicates that most charging will occur at residences, followed by charging at the workplace, and the least possible time for charging in publicly accessible locations.

Residential Charging

Most charging of PEVs takes place at residences because a vehicle is typically parked at a residence for the longest portion of the day, typically over 12 hours/day (see Figure 3-5). According to the 2011 American Housing Survey, about 63 percent of housing units (both single-family and multifamily units) in the United States have access to a carport or garage, and most of those units are occupied by the owners (U.S. Census Bureau, 2012).[2] In those cases, the charging infrastructure would be controlled by the property owners. AC Level 1 charging should suffice for vehicles that have small batteries and electric ranges, such as the Toyota plug-in Prius, or for vehicles that are driven primarily short distances. No infrastructure beyond a dedicated 120-V circuit capable of delivering 15 to 20 A would be needed. Because most garages or carports have external outlets that could be used, there would be no need to install additional infrastructure. However, multiple PEVs at the same residence might require additional infrastructure if there is only a single-car garage or carport or a single outlet. Furthermore, if PEV owners want to take advantage of special rates for PEV charging and to track their use better, they might need a separate circuit, even for AC Level 1 charging.

[2] Among the 37 percent of housing units that lack access to a garage or carport, 83 percent have a driveway or off-street parking available (U.S. Census Bureau, 2012). Such off-street parking may offer access to a dedicated 120-V circuit.

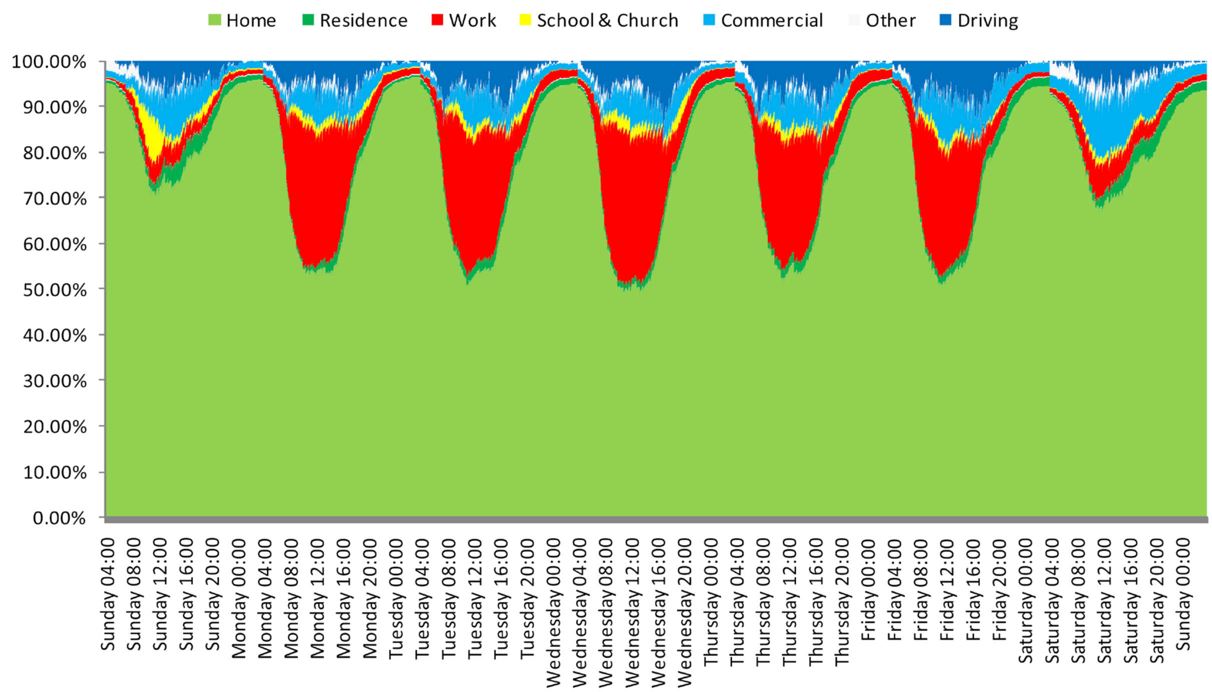

FIGURE 3-5 Distribution of vehicle locations throughout the week on the basis of data from the 2001 National Household Travel Survey. SOURCE: Tate and Savagian (2009). Copyright 2009 by SAE International. Reprinted by permission.

The recommended charging method for vehicles that have a longer electric range, such as the Nissan Leaf, is AC Level 2 charging. It usually can be completed easily during the time spent at the residence and can even be rapid enough to take advantage of lower late-night electricity rates where these are available. Dedicated 20-A service is required for some vehicles, such as the Chevy Volt and the 2012 Nissan Leaf, which require up to 15 A to charge. Dedicated 40-A service is required for the faster-charging vehicles, such as the 2013 Nissan Leaf, which can accept up to 30 A. Most single-family residences have 240-V electric circuits that can deliver up to 100 A. For those residences, a circuit that can deliver 15 or 30 A to a charging vehicle should be available unless many large electric appliances are being used. In its final report, the committee will consider the additional requirements for charging vehicles that have larger-capacity batteries.

Recent analysis provides further insights into the potential for residential charging. On the basis of a Web-based survey, Axsen and Kurani (2012) estimated that about half the new-car-buying U.S. households have residential access to a 120-V electric outlet within 25 ft for at least one vehicle. They also estimated that about one-third of new-car-buying households in San Diego County have access to a 240-V outlet capable of providing AC Level 2 charging. Traut et al. (2013) estimated that although 80 percent of households have some off-street parking, only about half the vehicles have access to a dedicated parking spot at an owned home where a charger could be installed.

One potential barrier to residential charging is the cost of an AC Level 2 charger[3] and its installation, which typically adds an average of $1,375 (range, $1,100 to $1,800) to the initial cost of a vehicle that is already more expensive than a comparable conventional vehicle (Francfort, 2012). As noted by Francfort, the costs vary by geography; for example, locations in California have higher than

[3] Strictly speaking, the location of the charger for AC Level 2 is on the vehicle itself and not mounted on the unit. Thus, the correct term would be *AC Level 2 EVSE*. However, *AC Level 2 charger* is commonly used.

average costs. Other factors that affect installation costs include the amount of carpentry and concrete required and the age of the house stock. For example, if a residence has only 60-A service or only 120-V circuits, which might be the case in older homes, the cost of upgrading the service can make installing AC Level 2 charging much more expensive. Francfort also noted that permit fees, although they typically cost about $50, can cost as much as $500 and thus become an important part of the installation costs. A recent report by the California Plug-in Electric Vehicle Collaborative (2012) identified a need to streamline the permitting system for installing residential chargers. Some federal and utility programs have subsidized the installation of chargers or provided them free. The installation costs currently can be partially deducted from federal income taxes. Although vehicle dealers provide guidance and potential discounts on vehicle chargers, the cost of the chargers cannot be financed as part of the vehicle.

One substantial barrier to residential charging is the need to provide charging infrastructure for residences that have access only to street parking or shared parking lots where installation of such infrastructure is beyond the control of drivers. Retrofitting existing facilities is one option for multifamily units that have dedicated parking. However, a much less expensive option is at least to prepare for the possibility of installing chargers during initial construction. Workplace and publicly accessible charging opportunities might be a substantial help to some PEV owners who lack access to charging infrastructure at their residences. Another option is to restrict parking spaces for PEVs to those with special permits and to recover charging-installation costs through the sale of permits for the spaces. Having dedicated parking spots for PEV charging, however, might be problematic in highly urbanized locations that already have too little parking available.

Workplace Charging

Workplace charging provides a substantial opportunity to encourage the adoption of PEVs and increase the fraction of miles that are fueled by electricity. First, BEV drivers could potentially double their average range as long as their vehicles could be fully charged both at work and at home, and PHEV drivers could potentially double their all-electric miles. Second, workplace charging would allow commuters who lack access to residential charging the opportunity to commute with a PEV. Third, charging could help to increase electric-vehicle miles traveled by making it possible to reach destinations that currently exceed a vehicle's range before returning to a residence.

Figure 3-5 shows that a typical vehicle during a typical work week (Monday-Friday) is parked for about 8 hours at a workplace; this is consistent with the Bureau of Labor Statistics work-week estimate of the average adult spending 8.6 hours/day at work and in work-related activities (BLS, 2012). AC Level 2 is the best choice for most currently available PEVs that have a large electric range, although it might be prudent to design workplace charging infrastructure to accommodate possible increases in battery capacity.[4] AC Level 1 charging could be sufficient for the substantial fraction of workers who have short commuting distances if ways could be devised to prevent the theft of EVSE devices, which for current vehicles simply lie exposed on the pavement during charging. The U.S. Bureau of Transportation Statistics estimates that 68 percent of commuters travel 15 miles or less in one direction, and the National Household Travel Survey estimates that 70 percent of trips made to earn a living are less than 15 miles (BTS, 2003; FHWA, 2011). As indicated in Figure 3-1b, AC Level 1 charging would meet the needs of drivers who require only enough charge to make it back to their residences. The circuitry and charging infrastructure is much the same as for a residence except that the installation would be at a company parking lot or garage.

There are several barriers to workplace charging. A fundamental challenge is to determine how many PEVs will be present on what time scale, what level of charging would be sufficient for their needs, and how to ensure access to chargers as the number of PEVs increases. A worker who relies on

[4] The committee notes that it remains to be seen whether faster charging options at workplaces are needed or could be feasible without a large increase in cost.

workplace charging of his or her BEV might not be able to return home if no charger is available. Furthermore, the cost of installing chargers in existing parking lots and garages is substantial for AC Level 1 and AC Level 2 chargers. In addition to construction costs, there might also be costs associated with electricity service upgrades for the AC Level 2 chargers. However, a financial incentive, such as an accelerated depreciation schedule, might make businesses more willing to offer workplace charging. Another potential barrier is that electricity provided to employees must be paid for by the employees or taxed. The requirement to assess the value of the charging or report the imputed income could be an impediment to workplace charging. Yet another barrier is that utilities assess companies a surcharge for exceeding a threshold level of power. Demand charges can be substantial, depending on the total electricity used by a business. (Demand charges are discussed in more detail in Chapter 4.) A final possible barrier is that new BEVs will have larger batteries and thus could require more charging infrastructure than AC Level 2 chargers for full charging, although a full charge might not be required. Vehicles with 85-kWh batteries are available but only for expensive vehicles that will not be widely adopted in the short term. Furthermore, obtaining a full charge at a workplace might not be so critical for those vehicles.

Workplace charging is available at some companies, such as Google and Microsoft, which offer it as a way of attracting employees. Employers are adopting various models for providing workplace-charging infrastructure, including having employees pay for the cost of the infrastructure through a daily charge or offering it at no charge as an employee benefit. Alternative models for workplace charging clearly are needed, as is a better understanding of current and future charging demands and the most economical ways to meet employees' charging needs.

Publicly Accessible Charging

Federal and state efforts concerning vehicle charging have focused on the development of a charging infrastructure that is accessible to the public (Durst, 2012; Karner, 2012). This section describes the basic characteristics of publicly accessible charging and business models for developing such an infrastructure.

Basic Characteristics

Although most PEV owners rely primarily on residential charging (Francfort, 2012), the availability of charging in public places can enable drivers to extend the daily range of their vehicles beyond the mileage that can be driven on a single charge. Public charging can include AC Level 1, AC Level 2, and DC fast charging. The vast majority of public chargers are AC Level 2 chargers. DC fast chargers have been deployed in a few regions in the United States (Blink, 2012; DOE, 2013b). DOE estimates that over 6,500 AC Level 2 and 155 DC fast-charging stations are available to the public in the United States; some stations require users to be members of a subscription-based plan (DOE, 2013b). The bulk of the installed DC fast chargers are along two corridors: along the I-5 corridor in Washington and Oregon and in the "Tennessee Triangle" that connects Nashville, Chattanooga, and Knoxville. Other networks of DC fast chargers are deployed in southern California, Dallas-Fort Worth, Houston, San Francisco, Phoenix, and Chicago.

As shown in Figure 3-2b, AC Level 2 charging can add about 10 to 20 miles of range to a vehicle for each hour of charging, depending on the model and driving conditions. That option might be attractive for those whose batteries are not fully discharged or for those who plan a longer stay at some location, such as a restaurant or a theater. AC Level 1 charging might be an economical charging option for locations where drivers are parked for an extended period, such as an airport or train station. However, the public infrastructure for long-distance travel for BEVs will require DC fast charging, which allows drivers to charge to 80 percent of battery capacity in 30 min. Long-distance trips that are fueled only with electricity could be challenging or inconvenient for drivers who do not have time for at least one recharge of 20 to 30 min.[5] DC fast charging might be attractive for city driving that involves short parking times and long periods of driving. Furthermore, the availability of DC chargers could make it easier for BEV owners to use their vehicles more fully for intermediate-distance trips, such as weekend and evening noncommute trips.

In addition to providing relatively fast refueling, publicly accessible charging must be placed at convenient locations. The availability of publicly accessible charging (and consumer awareness of its availability) is critical for providing a safety net and mitigating concerns regarding vehicle range. Whether the public-charging infrastructure is effective in relieving range concerns and enhancing the attractiveness of BEVs will depend on the extent to which the charging infrastructure is dispersed around an area. For example, Nicholas et al. (2013) provides a model for locating DC fast-charging stations in California to supplement AC Level 1 and AC Level 2 charging to cover vehicle trips that are now driven by conventional vehicles. However, the committee notes that siting also depends on finding a willing location that has sufficient access to electric service and the ability to cover any demand-charge costs that might be incurred. Although data have been collected on charging behavior and on possible locations for publicly accessible charging stations (see, for example, Nicholas et al. 2011; Francfort 2012), more information on charging behavior will help planners and companies to decide where to locate charging stations, especially when they are trying to design charging corridors.

A key consideration in the deployment of public-charging infrastructure is cost. Although AC Level 1 and AC Level 2 chargers could be made available relatively inexpensively in many public places, DC fast chargers are expensive to install. The capital cost of a fast-charging station depends on the characteristics of the installation site. Important factors include whether the property must be purchased, leased, or rented; what distance must be spanned to connect to high-power supply lines; whether upgrades are required because of insufficient transformer or electric-panel capacity; how much trenching and conduit are needed to reach the charging station; and how much repaving or restriping of the parking area is required to accommodate the charging station. As a point of reference, Table 3-2 shows the average costs of installing charging stations in Washington state with DC fast chargers and AC Level 2 chargers as part of the publicly funded West Coast Electric Highway project. The committee recognizes that some costs might have changed since the project was completed. The basic equipment costs for a DC fast charger is about $10,000 to $15,000, but the figure quoted in Table 3-2 ($58,000) reflects the auxiliary services and features for a publicly accessible unit, including warrantee, maintenance, customer authentication, and networking and point-of-sale capabilities to collect payment from customers. Installation costs can also vary because of other enhanced safety and security measures that are often required by local permitting authorities, such as lighting and revenue-grade meters. Those options can add roughly $90,000 to the cost of the fast-charging equipment itself. Additional costs might also be incurred if multiple plugs are required for compatibility. Although a DC fast-charging station is not directly comparable with a gas station, it is interesting to note that the average cost of installing a new gas station has been estimated at about $2,000,000 in urban areas and $1,700,000 in rural areas (PB, 2009).[6]

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[5] Owners of the Tesla Model S, which has a substantially greater range, could overlap the requirement for a 30-min charge with their desires for food, rest, and other services. That is, a 30-min charge might not be considered inconvenient if the vehicle range is substantial.

[6] The committee makes this comparison merely to indicate that the scale of installing a DC fast-charging station is much smaller than the scale of installing a new gas station. It recognizes that gas stations typically have many pumps and dispensers and that refills are much faster. Public charging sites, whether they are DC fast-charging stations or AC Level 1 or 2 chargers, will need to install multiple chargers if the demand for services is sufficient to cause long wait times. Long wait times for public chargers could deter PEV drivers if they expect to depend on such facilities.

PREPUBLICATION DRAFT—Subject to Further Editorial Correction

TABLE 3-2 Average Costs of Installing Publicly Accessible DC Fast-Charging Stations for the West Coast Electric Highway Project (PB, 2009)[a]

Component	Cost
DC fast-charging equipment • 50-kW DC public fast-charging station (480-V ac input) • 3-year warranty and point-of-sale capabilities[b] • Payment of *all* electricity dispensed (including utility demand charges) • Overhead lighting and required safety equipment	$58,000 per unit
Level 2 charger colocated next to DC fast-charging station • 240-V/30-A AC Level 2 public charger • Same terms and conditions as listed above	$2,500 per unit
Equipment installation (labor and electric-panel upgrade) • Separate power drop or meter for the charging station • Electric-panel upgrade (if required) • Construction and environmental and electricity permits • Trenching, backfill, and site restoration • Installation of conduit and power lines to charging station • Installation of concrete pad and electric stub-out • Installation of curb or wheel stop and overhead lighting • Installation and testing of equipment	$26,000 per location
Utility interconnection • Costs are highly variable and depend on cost-recovery policies of the electric-power provider and condition of existing power-distribution components[c] • Generally includes utility costs for preliminary engineering and design, transformer upgrades, and labor for connection to the grid	$12,500 to $25,000 per location
Host-site identification, analysis, and screening • Identification of potential sites • Consultation with electric-power providers	$5,000 per location
Negotiation, legal review, and execution of lease • Making contact with several property owners • Exchanging and negotiating lease documents • Executing and recording documents	$6,000 per location
TOTAL FOR DC FAST CHARGER AND 3-YEAR SERVICE	**$109,500 to $122,000**

[a] Land costs are not included here.
[b] Point-of-sale capabilities might include radiofrequency identification authentication and networking to back-office functions (such as account management and customer billing), equipment status signals, and credit-card transactions.
[c] Additional costs could be incurred if addition of multiple chargers increases demand charges or requires additional electricity-service upgrades.

Models for Deployment of Publicly Accessible Charging

There are a variety of business models for deploying publicly accessible charging. As part of their early efforts to promote the deployment of PEVs, federal and state policy-makers sought to establish a "beachhead" of charging stations that would precede introduction of PEVs into the market in 2010 and beyond. Substantial federal funds were allocated via grants for charging infrastructure. In many cases, 100 percent of funding was provided without requirements to demonstrate a viable business model to support current operations or to expand the network of charging stations, and some question whether current approaches are cost-effective in achieving the desired goals (Peterson and Michalek, 2013). The motivation for public funding of infrastructure was to catalyze the deployment of PEVs and charging infrastructure. It was believed that the availability of publicly accessible charging infrastructure would convince people to buy PEVs and that having more PEVs on the road would motivate private entrepreneurs to provide publicly accessible charging.

Because of the mutual dependence of PEV sales and public infrastructure deployment, the societal benefits of wide-scale adoption of PEVs might not be realized without adequate deployment of publicly accessible charging. Continued public-private partnerships or other forms of government support might be required, especially if the objective is to provide DC fast-charging infrastructure necessary to support long-distance travel. In considering whether and how much to subsidize private investments in public charging stations or to enter public-private partnerships to build such stations, it is important to recognize that investments in publicly accessible charging infrastructure can indirectly promote PEV purchases through several channels. First, public awareness of and education about PEVs can be enhanced when governments decide to place publicly accessible chargers, including DC fast-charging stations, in highly visible areas. For example, Electric Avenue in Portland, OR, has six types of chargers for use. It is near a major university and transit facility and provides a venue for product demonstrations and briefings (Durst, 2012). Second, some evidence indicates that the mere placement of a DC fast-charging station mitigates BEV drivers' concerns about range issues (that is, running out of electricity) even if the drivers choose not to use the station. A study by the Tokyo Electric Power Company (TEPCO) demonstrated that an additional fast charger caused employees using BEVs to deplete batteries more than when only a single charger was available (Anegawa, 2008).

An important issue is how best to structure public initiatives that draw in private funding and maximize the "bang for government bucks." In seeking private contributions to the funding of publicly accessible charging stations, government agencies must be careful that their policies do not unduly intrude in the business space of infrastructure providers. Although early investors benefited heavily from government support, private investors now express concerns, for example, that federal or state governments might undermine their business potential by offering free charging or that government regulations may require them to install expensive data-collection devices at their charging stations. They also express concern that compliance with and lack of guidance on compliance with federal regulations, such as the Americans with Disabilities Act, could affect their businesses.

Partly in response to government incentives, several private companies have stepped in to fill the nascent needs for public charging. They are experimenting with different business and pricing models for profitability in recovering their capital costs and the costs of electricity. For example, ChargePoint is pricing on a per-charge basis, and ECOtality and eVgo/NRG are pricing on a monthly subscription basis (Krauthamer, 2012; Lowenthal, 2012). Other business models rely on advertising revenue in which a third party—such as Ford, a retailer, or a local business—pays the charging provider for the space to place an advertisement on the charging station, much as an advertiser pays for a billboard (see Figure 3-6) (Karner, 2012). Other business models for deploying charging infrastructure include the Tesla model, in which the vehicle manufacturer deploys the charging infrastructure, and the BetterPlace model, in which a depleted battery is swapped for a fully charged one and the driver pays a subscription fee that covers all electricity at all stations and the amortized (or leased) cost of the battery (Wolf, 2012).[7] Nissan has recently

[7] BetterPlace has recently announced that it is withdrawing from the North American and Australian markets.

announced plans to deploy a DC fast-charging station in an approach similar to Tesla's. Other business models include having utilities provide the charging infrastructure (see Chapter 4 for further discussion) and having business owners provide the charging infrastructure as an enticement to get customers into their establishments.

Permission pending

FIGURE 3-6 A Blink brand EVSE wrapped in a paid advertisement by Ford. SOURCE: Don Karner, ECOtality, presentation to the committee on December 18, 2012.

A major barrier to the deployment of publicly accessible charging infrastructure by private investors is the difficulty of achieving a favorable rate of return on investment from PEV charging alone. The problem is especially relevant for higher-cost DC fast-charging stations for which the committee is unaware of any case in which private firms have recovered the installation costs and received sufficient returns. Again for comparative purposes, gas-station owners are able to recover their larger capital costs for two reasons: (1) although competition compresses margins on gasoline sales, station owners have a much larger volume of purchasers, and this helps them to achieve at least small profits on that product; and (2) gas stations derive additional profits from the sale of convenience food and goods—about two-thirds of the gross profit of a gas station is derived from food and goods, even though fuel sales account for 3 times the revenue from in-store sales (PB, 2009). In contrast, the revenue streams from dispensing electricity at stand-alone fast-charging stations are now low and unpredictable for the future, and this calls into question their ability to achieve commercial viability. Publicly accessible charging also competes with drivers' home charging systems. At some price point, it might not be economical to charge a vehicle at a public station.

Given the relatively long time required to charge a PEV compared with fueling a conventional vehicle, publicly accessible charging is most likely to be used if it is available where drivers leave their cars parked. Charging providers have strong motivation to locate public charging where people spend time, such as malls, retailers, libraries, and airports. Some retailers view the stations as a way to draw customers and have been willing to cover the bulk of the costs. For example, one charging provider was contracted to install charging units at some Target stores, and Target bears the installation and maintenance costs. A store offers free charging to its customers to encourage them to spend more time shopping while they wait for their cars to charge. Target has estimated that the incremental revenue generated from the additional time in the store makes the investment profitable. In that business model, the charging infrastructure might require only AC Level 2 chargers that provide electricity for an additional 10 to 20 miles.

Finally, the public rationale and the private-business case for installing charging stations to enable travel between metropolitan areas are weaker than those for charging stations within metropolitan areas. In general, only 24 percent of total vehicle miles traveled in 2009 were on interstate highways (NHTSA, 2010). Governments can play an important role in assessing the case for electrification of transportation corridors between adjacent metropolitan areas (for example, along the Boston-Washington corridor or in southern Florida), and they would probably need to provide subsidies or enter public-private partnerships if such projects are undertaken. Such assessments could be informed by data on BEV traffic along the Washington and Oregon segments of Interstate 5. On the average, the DC fast chargers along the Washington corridor have been used less than twice a day in recent months, although the TEPCO study indicates that the safety net provided by the presence of chargers may have an important effect on BEV use between adjacent metropolitan areas.

FLEETS

A special case of charging-infrastructure needs involves the vehicle fleets owned and operated by corporations or federal, state, and local governments. There are several advantages of PEV adoption by fleets, including the emphasis on total cost of ownership rather than initial costs, route predictability, use of central parking facilities, and corporate sustainability (Electrification Coalition, 2010). The charging-infrastructure needs for fleets depend on their uses; some fleets rely on residential charging, and others on central parking facilities similar to sites of workplace charging. Where fleet vehicles sit idle overnight or for long periods during the day, AC Level 2 charging may provide a good solution for refueling. For many fleets, however, the need to charge a number of vehicles in the same fixed period or the business case for turning around vehicles quickly is likely to necessitate DC fast charging. Special challenges can arise when large numbers of vehicles parked near each other must be charged at the same time given the load that this can place on the electricity-distribution system and possible demand charges (see Chapter 4 for further discussion).

Several companies have made PEVs a component of their vehicle fleets. For example, General Electric announced in 2010 that it would purchase as many as 25,000 PEVs of which 12,000 were to be Chevrolet Volts, although recently the company has indicated that it would not purchase as many PEVs and would include other alternative-fuel vehicles (Catts, 2013). The company envisions that most charging of PEVs would occur at the residences of those using them.

Federal, state, and local governments can contribute to the deployment of PEVs by electrifying their own fleets. Such an initiative would increase PEV sales and increase the visibility of such vehicles. If electrifying their fleets reduces the operating costs of refueling and increases the capital costs of vehicles, it might require overcoming bureaucratic constraints on shifting funds between operating budgets and capital budgets. Some government agencies have a disincentive to include PEVs in their fleets in that the electricity charges are not allowed in their operating budgets although fuel charges are. In addition, the federal government could provide charging at its own facilities and encourage workers to buy PEVs, it could collect information and serve as a centralized source for consumer information, and it could play an important role in shaping standards if the General Services Administration became involved in a major effort to procure charging systems. Those possible roles will be considered more fully in the committee's final report.

Another type of fleet to consider is a rental-car fleet. Hertz offers several options for PEV rentals, including making the vehicles part of its typical rental-car fleet or offering more specialized programs, such as EV-On-Demand or car-sharing services (Hidary, 2012). As noted above, residential charging is potentially problematic for the roughly 37 percent of U.S. households that do not have garages or carports (U.S. Census Bureau, 2012). Use of PEVs by those households could be encouraged through the deployment of PEVs in rental-car fleets and initiatives to make PEVs available in convenient locations for car-sharing, as discussed below. For rental-car fleets, the businesses would need to consider such issues as reprogramming of Web sites to have a PEV option, reprogramming of capacity planning to have downtime for PEV charging, and pricing of vehicles to facilitate PEV experimentation.

The role of the government in facilitating deployment of charging infrastructure for fleets could include educational initiatives targeted at fleet operators and some combination of tax and depreciation incentives. As noted, the federal government also could spur sales and visibility of PEVs by converting some of its fleet to such vehicles and by providing charging at its own facilities, thus encouraging the deployment of PEVs and standardization of infrastructure though its procurement process.

SHARED-USE VEHICLES

Another special case of charging-infrastructure needs involves shared-use vehicles. In recent years, urban congestion, high gasoline prices, and information technologies have combined to encourage the emergence of shared-use vehicles. A handful of companies have entered the business of making vehicles available for sharing, and a couple offer programs based on electric vehicles. Car2Go (a Daimler subsidiary) offers rentals of electric Smart cars in several U.S., European, and Canadian cities. BMW's Drive-Now program also offers electric-car sharing in several U.S. and European cities. And in parallel with initiatives to integrate PEVs into their fleets, Hertz is developing a new business model, Mobility as a Service, which could lead it to offer a subscription-based service in which customers have access to vehicles of choice, including PEVs, at any time for a monthly fee (Hidary, 2012).

The trend toward shared-use vehicles—and perhaps also shared ownership of vehicles—might facilitate the use of PEVs. Shared-use options might prove to be particularly attractive to U.S. households that want to drive PEVs but do not have garages or carports where they can conveniently charge their cars overnight and to younger people, partly because they tend to be more affected by income constraints, urban congestion, and lack of residential charging facilities. Young people also tend to be more adept at (and comfortable with) using the information technologies that are relied on in managing the vehicle-sharing process. The potential for shared-use vehicles to increase the number of electric miles traveled and the potential role of the federal government in encouraging shared use of PEVs—other than to monitor and be ready to modify policy as trends emerge—are not entirely clear.

FINDINGS AND POSSIBLE GOVERNMENT ROLES IN THE CHARGING INFRASTRUCTURE

A fundamental impediment to developing and assessing policies to overcome barriers to the deployment of PEV charging infrastructure is an understanding of the charging needs of PHEV and BEV drivers and how the needs might change. Those needs are affected by the types of PEVs on the road and their travel patterns. The federal government—through its continuing efforts to collect, analyze, and disseminate data on vehicle charging, PEV sales, and policy effectiveness—could help to address the data gaps. Its analysis could include research to understand the effects of installing charging infrastructure on economic and related activity. The committee's final report will investigate further the extent to which AC Level 1, AC Level 2, and DC fast charging meet residential, workplace, and publicly accessible charging needs.

Residential Charging

There are no serious technical barriers to the installation of residential charging infrastructure at most residences that have access to garages or carports. Charging at such residences, although installation and permitting of an AC Level 2 charger are expensive (about $1,100 to $1,800; Francfort, 2012), meets the needs of overnight charging of all foreseeable PHEVs and of BEVs that have a range of about 100 miles. AC Level 1 charging appears to be adequate for overnight charging of many PHEVs and of BEVs that are not driven extensively, and it will not require any modifications of many existing residences. The main barrier to the widespread adoption of residential charging of PEVs for such housing units seems to be the cost and effort of installing the outlet and, more fundamentally, the cost of the vehicle itself. An important barrier to PEV adoption is the lack of access to residential charging infrastructure, which can be the case for people who lack garages or carports, especially in multifamily dwellings or high-density locations. Retrofitting buildings that were not constructed with PEV charging as a possibility can be expensive. Possible roles for the federal government in reducing the barriers to residential charging of PEVs are

- Continuing tax incentives and subsidies for installation of residential charging units, including those for multifamily units.
- Encouraging state and local governments to streamline the permitting for residential charging and to adopt building codes that mandate that new construction be PEV-charging-enabled.
- Helping to enable housing units that lack access to garages or carports to have better access to charging by encouraging or subsidizing local governments to have dedicated parking spots or by providing other incentives to install chargers.
- Continuing efforts to understand charging needs and future requirements through collection and analysis of charging and PHEV and BEV sales data by the federal government and through support and collaboration with researchers who are collecting and analyzing such information.

Although all the above options would encourage residential charging, the committee recognizes that any continuing federal subsidies and incentives come at a monetary cost. Tax incentives add complexities to the tax code. Federal research efforts, including the support of external researchers, also come at a cost, albeit a smaller one. And the committee recognizes that many of the efforts will require initiatives not from the federal government but from state and local governments. In those cases, the federal government's role would be to analyze data and policies and to disseminate information to the public, businesses, state and local officials, and other stakeholders. The federal government could also use its convening function to facilitate interaction and coordination among stakeholders.

Workplace Charging

Increasing the availability of workplace-charging infrastructure potentially offers an important opportunity to encourage the adoption of PEVs. At workplaces, vehicles are typically parked for 8 hours or longer each day during the workweek. Over such a time, AC Level 2 chargers could provide a substantial amount of vehicle range, and AC Level 1 chargers might be sufficient for many PHEVs and for BEVs that are used for short commutes. Workplace charging also might be a charging solution for PEV owners who do not have access to charging at their residences. Possible roles for the federal government are

- Providing a financial incentive, such as an accelerated depreciation schedule, to give businesses an incentive to offer workplace charging.
- Exempting electricity provided by workplace charging infrastructure from being treated as a taxable benefit.

- Working with utilities and their regulators to minimize demand charges that might be incurred because of workplace charging of PEVs.
- Continuing efforts to understand workplace charging needs and future requirements and disseminating information on examples of installations to illustrate costs, installation requirements, and possible methods to recoup installation costs or deal with tax implications.

All the above options would encourage further deployment of workplace charging. The committee recognizes that the disadvantages include the monetary costs that come with providing subsidies or supporting analysis, that developing accelerated depreciation schedules for the installation of workplace-charging infrastructure increases tax-code complexities, and that efforts associated with how utilities assess demand charges lie with the utilities and their state regulators. Similarly, the decision on whether to pass the costs of workplace charging on to employees or to internalize the costs lies with employers. As with residential charging, the federal government's roles in policies that lie outside its direct domain would be to analyze data and policies; to disseminate information to the public, businesses, state and local officials, and other stakeholders; and to facilitate coordination among them.

Publicly Accessible Charging

Concerns about the availability of publicly accessible charging may restrict wide-scale adoption of PEVs. Adequate deployment of public-charging infrastructure in the near term might require public-private partnership or other forms of government support. In the middle to long term, a sustainable business model is needed. Although publicly accessible charging provides opportunities for briefer charging than residential and workplace charging, it offers several important benefits, including extending the electric range of all PEVs, relieving range concerns of BEV owners, and providing increased visibility for both PHEVs and BEVs.

Possible roles for the federal government include

- Providing continued incentives to support the deployment of publicly accessible charging, especially demonstration projects that propose credible and creative business models that could eventually be sustained when subsidies are no longer available.
- Providing increased clarity and simplicity regarding regulatory compliance, such as compliance with the Americans with Disabilities Act and data-collection requirements.
- Incentivizing landowners, retailers, and public agencies to offer host sites for the installation of public charging stations in key highway corridors.
- Continuing efforts to understand public-charging needs, future requirements, and the extent to which publicly accessible charging encourages PEV adoption and increases the number of electric miles driven.

The committee recognizes the disadvantages of continuing to have federal and other subsidies involved in the deployment of publicly accessible charging infrastructure, including the monetary cost and the potential to exclude or discourage private investors. It also recognizes that there is little understanding of the extent to which incentives to deploy publicly accessible charging encourage PEV adoption or increase the number of electric miles driven.

Fleets

Fleets of PEVs have the potential to increase consumer awareness and adoption of such vehicles if cost-effective ways to charge large numbers of vehicles at the same time and close to each other can be found. PEV fleets increase the sales of such vehicles by automobile manufacturers and thus can help to reduce the costs through increased sales volume. The role of federal, state, and local governments could include providing incentives to encourage the adoption of electric fleets and the installation of the required charging infrastructure. Governments could also increase sales by purchasing such vehicles as part of their fleets and by modifying accounting rules to allow electricity costs for PEVs to be treated in a manner similar to how gasoline costs are treated for conventional vehicles. The federal government could play a specific role by providing charging at its own facilities and thus encouraging the deployment of PEVs and standardization of infrastructure though its procurement process. The added initial purchase costs and costs for needed charging infrastructure are disadvantages of increasing the use of PEVs in the federal government's vehicle fleet.

Standardization of the Charging Infrastructure

The committee recognizes the importance of standardization of many facets of the infrastructure and concludes that multiple plugs for DC fast chargers and the lack of standardization of payment methods for different charging networks are particularly problematic. It recognizes that the federal government typically looks to professional societies or standard-setting organizations to develop common technology standards. However, an appropriate role for the federal government would be to play a convening role to encourage standardization of charging plugs and payment methods. A disadvantage of such standardization is that it might have the potential to restrain innovation, although increasing the interoperability of charging networks and plugs increases the coverage for the whole charging infrastructure.

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4

The Electric Grid

An important component of the ecosystem of the plug-in electric vehicle (PEV) is the electric grid, which provides the electricity that powers the vehicle. For the near term, PEVs do not pose unmanageable problems for the distribution, transmission, and generation components of the electric grid. For the longer term, successful integration of the smart grid and the smart electric vehicle could improve the services offered by both.

This chapter examines how PEVs affect the electric grid and other issues related to the electric grid that might be barriers to PEV adoption. It discusses possible roles of the federal government in overcoming the barriers. There might be additional grid-integration issues of interest for PEVs (such as the use of PEVs in smart grid applications), but these issues are not addressed in this report because they are beyond the committee's charge for its interim report and do not necessarily constitute barriers. Grid-integration of PEVs might enable the provision of additional services by utilities, particularly if achieved on a large scale; any issues pertaining to these new potential applications will be addressed fully in the committee's final report.

THE ELECTRIC GRID AND ITS INTERACTION WITH PLUG-IN ELECTRIC VEHICLES

PEV recharging causes a new kind of service demand for the electric grid. Specifically, the cost and nature of service vary sharply with the time of day when the service is required and with the power demanded. The electric grid can be thought of as having three components: *distribution* wires and transformers that serve individual houses, streets, and neighborhoods; *transmission* infrastructure that moves power from generating units to the local distribution system;, and *generation* units that provide the energy to the grid (Figure 4-1).

PEV adoption does not now pose a substantial problem for the distribution, transmission, and generation components of the electric grid. Studies have shown that the existing generation and transmission capacity of the nation could accommodate 5 to 50 million PEVs, depending on which strategies are used to manage the charging demand (Hadley and Tsvetkova, 2008; Kintner-Meyer et al., 2010; MIT, 2010). The energy and total capacity required for charging PEVs under some conditions can be of the same magnitude as the capacity of individual components of the distribution system, but this has not proved to be a major issue (CAIOUs, 2012). Local distribution infrastructure typically is sized to manage the peak electricity demand of a few houses. If PEVs were to be charged at the same time as those houses typically used the most electricity, there would be a potential for overloading elements of the local distribution system and thus a need for local upgrades. However, upgrading local infrastructure is a continuing activity of utilities as load patterns change owing to growth in units of demand or to changes in patterns of demand, such as could occur with increased adoption of PEVs.

Given the studies noted above and the practice of continuing infrastructure upgrades, the committee does not consider consumer PEV adoption to present an issue for the electric grid or specifically for the distribution system. The main exception would be adoption concentrated on a single distribution branch circuit—as would occur with a fast-charging station, dense clustering of private PEV-owner charging, or a fleet-charging facility—which could require an upgrade.

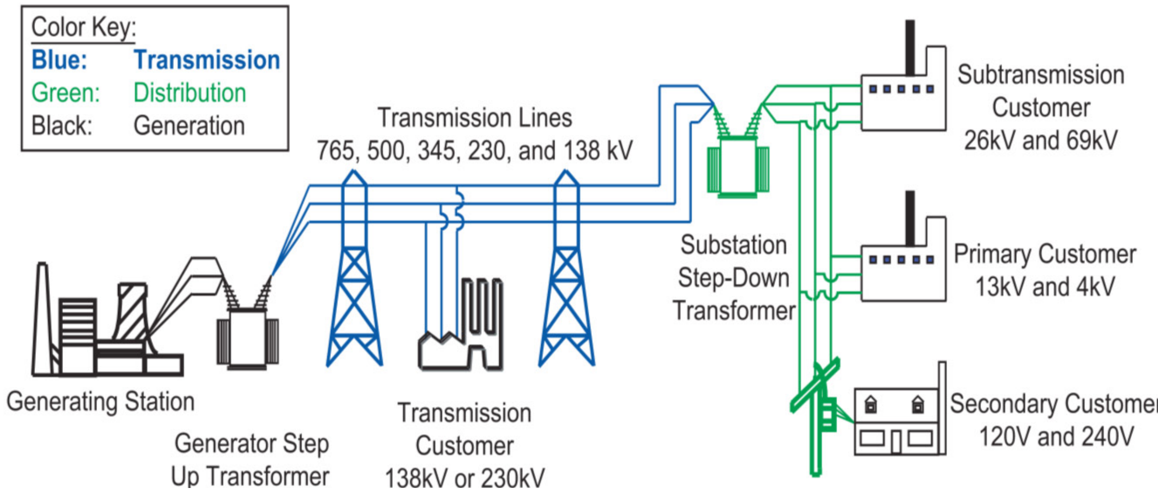

FIGURE 4-1 Basic diagram of the electric power delivery system. SOURCE: U.S.-Canada Power System Outage Task Force, 2004.

However, characteristics of the electric grid could have substantial effects on consumer adoption. They include rate structures, regulation of charging-service providers, levels of participation of utilities in charging-infrastructure investment, allocation of distribution-upgrade costs, and the amount of greenhouse gas (GHG) emissions from using PEVs. Those topics are discussed below.

UTILITY POLICIES THAT POTENTIALLY AFFECT ADOPTION OF PLUG-IN ELECTRIC VEHICLES

The price and availability of electricity for PEVs will be significantly influenced by decisions made by utilities and utility regulators. The outcomes of these decisions will affect the cost of and willingness of individuals and corporations to install PEV chargers and therefore can create barriers to or potentially accelerate PEV deployment (Baumhefner et al., 2012a). This section describes potential barriers related to utility policies and decisions.

Rate Structure

Utility rates are designed to recover the fixed and variable costs of a utility's generation of power and operation of the electric grid in a safe and reliable manner. Utility-rate design typically uses three primary constructs to recover the costs of operating the grid: volumetric charges (in kilowatt-hours), demand charges (in kilowatts), and fixed charges. Fixed charges can be used in the rates for all customers and are intended to recover the fixed costs of operating the electric grid, such as the investment needed for transmission and distribution infrastructure. In addition to fixed charges, residential customers most often have volumetric rates, whereas larger commercial and industrial customers are frequently billed on both a demand and a volumetric basis. Volumetric rates can be fixed (a constant price per kilowatt-hour that is independent of when power is consumed) or variable with time (for example, peak and off-peak time-of-use rates). Demand charges are applied most often to large consumers and are meant to recover the cost of physical assets needed to supply and deliver electricity. Demand charges often are based on the instantaneous highest demand (in kilowatts) for the customer site in a rolling 12-month period, but many other structures exist (see Box 4-1). However, utilities have different rates, and there is little or no consistency between utilities.

A rate structure that is attractive to both customers and utilities for PEV charging is one in which the rate is time-varying—time of use or real time—and the vehicle owner is able to schedule charging to take advantage of the generally lower off-peak rates. The EV Project sponsored by the Department of Energy (DOE) has demonstrated that PEV owners respond to time-of-use signals, substantially delaying their charging to times when there is lower demand for electricity (see Figure 4-2). Numerous other studies have also shown the ability of time-of-use pricing to reduce residential peak use (Barbose et al., 2004; Faruqui and Sergici, 2009; Allcott, 2011).

BOX 4-1 Demand Charges

The distinction between power (measured in kilowatts) and energy (measured in kilowatt-hours) is central to an understanding of the cost of electricity. The rate of delivery of energy to a customer is measured in kilowatts. Kilowatt-hours are used to indicate the amount of energy delivered over a specified period. Both energy and power demands require distinct capabilities of the electric grid, and the utilities must recover the costs of meeting those needs.

Introducing electric vehicles imposes an electric load with special characteristics. Consider, for example, a Chevrolet Volt recharging on a 240-V, 30-A circuit (AC Level 2). The amount of electricity consumed for a 10-kWh recharge would cost around $1.10 at a retail price of $0.11/kWh. But the power load is equivalent to that of a single home in areas like San Ramon, CA (May and Johnson, 2011). Because utility circuits and transformers tend to be sized to accommodate only a few homes, a small number of vehicles can change the power loading of a circuit markedly. For DC fast charging, the power load can be even greater, upwards of 50 kW, meaning that although individual vehicles might draw only a small amount of energy for a single charge, there can be short periods of substantial power use for charging-service providers. Upgrades of the local distribution infrastructure might be required if the electric-vehicle charging load occurs at the same time as the maximum electricity demand for a given section of the grid, as would be the case for any other type of electric load. For that reason, utilities have historically provided an incentive to customers to distribute their electricity consumption evenly throughout the day by imposing *demand charges* that are intended to reward customers with flat, unvarying loads during the day and penalize customers that have "spiky" electricity load consumption during the day.

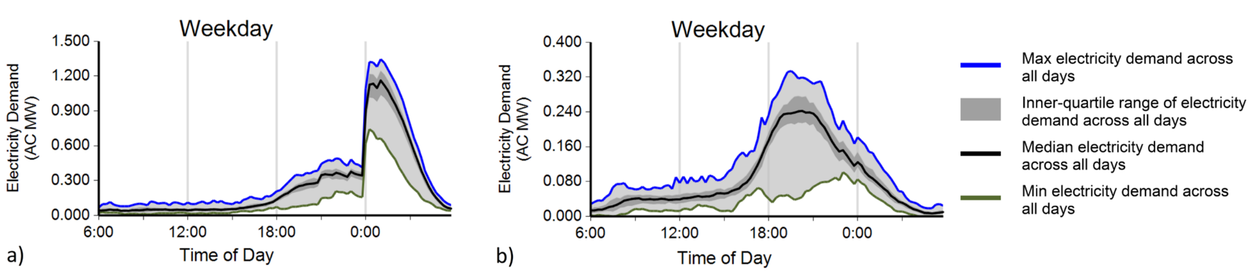

FIGURE 4-2 Aggregate electricity demand from plug-in electric vehicles in (a) San Francisco and (b) Nashville. Note that in San Francisco the bulk of the demand is shifted until after midnight, when an off-peak rate is in effect, indicating that a substantial number of consumers are postponing charging events until midnight. SOURCE: ECOtality, 2012.

Well-designed utility policies can play a critical role in minimizing costs and avoiding potential adverse grid effects associated with vehicle charging (Baumhefner et al., 2012a). From the utility and customer perspectives, rates that provide incentives for off-peak charging have the smallest effect on the utility infrastructure and the lowest cost per kilowatt-hour charged to PEV owners. At the other end of the spectrum, utility rates that include demand charges are the least favorable to charging of PEVs inasmuch as a single high-demand event, such as charging at midday on a hot day when air-conditioning is being used, can adversely affect a PEV owner's rate structure for an entire year.

A recent dialogue group convened by the Center for Climate and Energy Solutions (C2ES) that included charger-service providers, utility regulators, and utilities recommended that public utility commissions not treat PEV charging any differently from comparable loads (such as hot tubs and central air conditioning) when deciding whether demand charges should apply. In general, that would mean that PEV-specific demand charges should not apply to residential customers but might apply to commercial or industrial charging (C2ES, 2012). In a recent decision, the California Public Utilities Commission (CPUC) also chose not to adopt PEV-specific demand charges for residential PEV loads, citing similar reasoning (CPUC, 2011).

Utility Rates and Possible Roles of the Federal Government

Because decisions regarding retail rates are in the jurisdiction of state regulators and many states have not started proceedings regarding the treatment of PEV loads, there is a lack of a uniform national policy regarding the best rate structure that equitably recovers the costs associated with PEV loads (C2ES, 2012). To reduce barriers to PEV infrastructure and attempt to ensure equitable cost-recovery treatment, federal agencies could coordinate with state regulators, the National Association of Regulatory Utility Commissioners (NARUC), and other stakeholders to develop national rate-structure guidelines for PEV loads that allow reasonable recovery of costs of providing service to PEVs while not hindering PEV adoption or installation of PEV infrastructure.

In addition, the Federal Energy Regulatory Commission and DOE could convene discussions with NARUC and other stakeholders and analyze the benefit of time-varying rates for PEV owners and utilities. The results of such analysis should be made readily available to PEV owners or potential buyers to complement any other information that the utility provides on PEVs. Carefully managed charging is likely to be crucial for minimizing the effect of widespread PEV adoption, so it is important to give PEV owners extensive information on optimal pricing scenarios.

Treatment of Charging-Service Providers and The Role of Utilities in the Charging-Service Market

The treatment of charging-service providers as utilities is a potential barrier. State public utility codes often define *electric utility* in broad terms. There is uncertainty as to whether PEV charging-service providers will be treated as utilities, that is, as retail sellers of electricity that are subject to state regulation or simply as commercial customers that sell a service that uses electricity as a factor of production. That uncertainty could act as a barrier to PEV-infrastructure deployment because regulating PEV charging-service providers as utilities could result in higher costs and decrease business-model flexibility at this formative stage in the market (C2ES, 2012). NARUC (2011) and the CPUC (CA AB631 [2011]) have decided that PEV charging-service providers are not utilities, although they resell electricity. Those decisions were made to encourage business-model flexibility and to preserve PEV-owner safety through explicit acknowledgment that the utility commission can still exercise other powers to ensure the environmental performance and integrity of the electric grid (CA AB631 [2011]).

Whether utilities should be allowed to compete with third-party providers to provide residential or commercial charging is another important issue. Proponents of restricting utilities' access to the market argue that utilities have some important advantages over third-party companies. For example, utilities determine where the electricity infrastructure is located, can reduce their risks by recovering their costs from their investments, and are assured revenues from other electricity sales (C2ES, 2012).[1] However, utility investment can be viewed as a positive in that it is an existing sustainable path to deploy publicly accessible charging infrastructure.[2] Many third-party providers, however, argue that they could offer cheaper and more efficient service and emphasize that a competitive marketplace will promote innovation and high-quality service (C2ES, 2012). There is no consensus as to what the role of utilities should be in providing charging infrastructure.

CLEAN ENERGY, THE ELECTRIC GRID, AND POSSIBLE ROLES OF THE FEDERAL GOVERNMENT

Early adopters of new technology are more likely to purchase PEVs if the electricity that powers them is considered "clean" as many PEV early adopters are buying PEVs for environmental concerns (Accenture, 2011; Turrentine et al., 2011; Kurani et al., 2012). Emissions from the additional electricity mix needed to charge PEVs vary temporally and regionally; thus, different times and regions have different generation mixes (Kintner-Meyer et al., 2010), and this makes managed charging of vehicles crucial for minimizing their emissions (Peterson et al., 2011). Generally, the amount of GHG emissions generated in producing the additional electricity required to charge a PEV fleet is less than that generated by conventional vehicles, and criteria pollutants also will tend to be reduced in most areas (EPRI/NRDC, 2007; Kammen et al., 2009; Elgowainy et al., 2010).[3] It should also be noted that the manufacture and production of PEVs might result in emissions beyond those from conventional vehicles (Samaras and Meisterling, 2008; NRC, 2010; Michalek et al., 2011); however, those emissions are considered less of a barrier to deployment than the well-to-wheels emissions, and that topic is left for further discussion in the committee's final report.

There are various methods for owners to obtain clean electricity directly, including installing photovoltaic panels or purchasing renewable energy from their electricity provider (Baumhefner et al., 2012b). For customers that do not have access to clean electricity, the general environmental benefit of using electricity to charge PEVs might be a concern. One solution is for PEV drivers to purchase renewable-energy credits (RECs), and at least one company is offering to purchase RECs on behalf of its battery electric vehicle customers (Baumhefner et al., 2012b).

Another way to ensure greater GHG benefits of charging PEVs is to make the overall generation mix cleaner. Many states have adopted renewable-portfolio standards to decrease GHG emissions from the electric grid. Such efforts will continue to reduce emissions from the grid over the long term and increase the opportunity for GHG reductions from PEVs. The federal government has many options for continuing to encourage the adoption of renewable-energy sources and the conversion from coal plants to power-generation sources that have lower life-cycle emissions. Options include federal tax credits for installing renewable-power sources, preferential treatment in wholesale electricity markets, a national

[1] A recent dialogue group convened by C2ES that included PEV charging-service providers, utility regulators, and utilities recommended the following: "Utilities wishing to act as a PEV service provider should do so through unregulated affiliates as the use of ratepayer dollars could provide utilities with an unfair competitive advantage. Further, utilities should be allowed to own and operate EVSE for internal use, for demonstration purposes, and in areas that the private market would not support otherwise" (C2ES 2012, pp. 16-17).

[2] NARUC recommends not limiting utility access: "NARUC supports a competitive… marketplace, where utility companies, businesses, governments, and third-party service providers are able to participate in the owning, leasing, operating, or maintenance of charging or fueling equipment"(NARUC 2011).

[3] To the extent that the electricity is generated by coal-fired generation plants, there are potentially slight increases in mercury and airborne particulates.

price for GHG emissions, a federal standard for carbon emissions from power plants, and a nationwide renewable portfolio standard. The federal government has previously used tax credits and preferential treatment to encourage renewable-resource installations and could also do so by procuring green power for federal facilities.

Finally, the federal government could create or encourage marketing campaigns to ensure that potential PEV customers are aware of the GHG benefit of converting to PEVs.

LOCAL ELECTRICAL CODE REQUIREMENTS

Virtually all states and localities have adopted the National Electrical Code (NEC), which is developed by the National Fire Protection Association (NFPA). The NEC is approved as an American national standard by the American National Standards Institute (ANSI) as ANSI/NFPA 70. Specific elements of the code are tightened in some regions.

The NEC 625.13 *Electric Vehicle Supply Equipment Connection* covers the requirements for connection at residential level 1 or 2. AC Level 2 charging requires installation of a 240-V supply. Installation of a new 240-V circuit is subject, in all identified local building codes, to the NEC. Which permit is required is a function of whether the installation is associated with new construction or an existing residence. If it is new construction, the cost of the 240-V circuit is incorporated into the cost of the construction permit and is inspected as part of that process. For an existing residence, a permit is generally required at a cost of about $50 for the permit and inspection, although some regions have seen permit fees as high as $500 and as low as $7.50 (Francfort, 2012).

Data from the EV Project indicate that the total cost of installing an AC Level 2 charger ranges from $1,100 to $1,800 (Francfort, 2012). Given the cost of installation, any costs associated with permitting or inspection are minor and therefore do not constitute a barrier to adoption today, nor are they expected to constitute a barrier in the future.

FINDINGS ON THE ELECTRIC GRID

- The existing electric infrastructure does not present a barrier to the expansion of PEV technology in the United States given the projected growth of PEV use in the next decade. With the exception of a scenario in which a concentration of PEVs appears in an overburdened branch of the distribution system, no major physical barriers have been identified. As PEVs become a more significant share of total electricity consumption, the committee foresees no issues at the distribution level that cannot be handled through the normal processes of infrastructure expansion and upgrades in the electric-utility industry.
- The current time-based (time-of-use or real-time pricing) rate structures available to most commercial and industrial customers and some residential customers are an incentive to PEV owners and utilities in that they encourage charging at times when there is lower-cost generating capacity available and thereby reduce cost effects on the grid.
- Regulating third-party entities (nonowner, nonutility charging-service providers) as utilities could increase operating costs and decrease business-model flexibility.
- The role and scope allowed to utilities (compared with third-party entities) in providing charging equipment are unclear.
- The lack of access to or price premium for clean electricity could be a barrier to PEV adoption. However, there generally is a net benefit of using PEVs rather than conventional vehicles even with the existing generation mix. The benefit can be increased by a continued transition to generation sources that have lower life-cycle emissions.
- Local building codes based on the national building code are not seen to be a barrier to the development of the PEV market.

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Appendix A

Biographic Information on the Committee on Overcoming Barriers to Electric-Vehicle Deployment

John G. Kassakian, *Chair,* is a professor of electrical engineering and former director of the Massachusetts Institute of Technology (MIT) Laboratory for Electromagnetic and Electronic Systems. His expertise is in the use of electronics for the control and conversion of electric energy, industrial and utility applications of power electronics, electronic manufacturing technologies, and automotive electric and electronic systems. Before joining the MIT faculty, he served in the U.S. Navy. Dr. Kassakian is on the boards of directors of a number of companies and has held numerous positions with IEEE, including founding president of the IEEE Power Electronics Society. He is a member of the National Academy of Engineering, a fellow of IEEE, and a recipient of the IEEE William E. Newell Award for Outstanding Achievements in Power Electronics (1987), the IEEE Centennial Medal (1984), and the IEEE Power Electronics Society's Distinguished Service Award (1998). He is a coauthor of the textbook *Principles of Power Electronics* and has served on a number of National Research Council committees, including the Electric Power/Energy Systems Engineering Peer Committee, the Committee on Assessment of Solid State Lighting, the Committee on Review of the 21st Century Truck Partnership Phase 2, the Committee on Review of the Research Program of the Partnership for a New Generation of Vehicles, and the Committee on Review of the FreedomCAR and Fuel Research Program. He has an ScD in electrical engineering from MIT.

David L. Bodde is an engineering professor and senior fellow in Clemson University's International Center for Automotive Research. Before joining Clemson University, Dr. Bodde held the Charles N. Kimball Chair in Technology and Innovation at the University of Missouri–Kansas City. He serves on the boards of directors of several energy and technology companies, including Great Plains Energy and the Commerce Funds. His executive experience includes being vice president of Midwest Research Institute and president of MRI Ventures, assistant director of the Congressional Budget Office, and deputy assistant secretary in the U.S. Department of Energy. Dr. Bodde often testifies before congressional committees. He holds a doctorate in business administration from Harvard University, MS degrees in nuclear engineering and management from the Massachusetts Institute of Technology, and a BS from the U.S. Military Academy. He served in the Army in Vietnam.

Jeff Doyle has been director of public-private partnerships for the Washington State Department of Transportation (WSDOT) since July 2005. He oversees a program that develops partnerships with the private sector to advance transportation projects, programs, and policies. His office implemented the West Coast Electric Highway, a partnership project that provided the nation with its first border-to-border network of fast-charging stations for electric vehicles. Mr. Doyle also serves as cochair of Washington's Plug-In Vehicle Task Force, as a member of the Puget Sound Regional Council Electric Vehicle Infrastructure Advisory Committee, and as a member of the National Cooperative Highway Research Program Project Panel 20-83 (04), "Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on Transportation." Other current public-private partnership projects include redeveloping public ferry terminals, providing transit-oriented development with advanced traveler-information systems at state-owned park-and-ride facilities, and implementing alternative finance and funding mechanisms for transportation infrastructure development and maintenance. Before joining WSDOT, Mr. Doyle served as staff director and senior legal counsel to the Transportation Committee in the Washington legislature, where his work focused on transportation-policy, finance and freight-mobility issues. He is a member of the Washington State Bar Association and serves on the Supervisory Committee of a state-chartered credit union in Washington. Mr. Doyle earned a BA in political science from Western Washington University and a JD from Seattle University.

Gerald Gabrielse is Leverett Professor of Physics at Harvard University. His previous positions include assistant and associate professor, University of Washington, and chair of the Harvard Department of Physics. His research focuses on making accurate measurements of the electron magnetic moment and the fine structure constant and on the precise laser spectroscopy of helium. Dr. Gabrielse also leads the International Antihydrogen TRAP (ATRAP) Collaboration, whose goal is accurate laser spectroscopy with trapped antihydrogen atoms. His many awards and prizes include fellowship of the American Physical Society, the Davisson-Germer prize of the American Physical Society, the Humboldt Research Award (Germany, 2005), and the Tomassoni Award (Italy, 2008). Harvard University awarded him its George Ledlie Research Prize and its Levenson Teaching Prize. His hundreds of outside lectures include a Källén Lecture (Sweden), a Poincaré Lecture (France), a Faraday Lecture (Cambridge, U.K.), a Schrödinger Lecture (Austria), a Zachariasen Lecture (University of Chicago), and a Rosenthal Lecture (Yale). He is a member of the National Academy of Sciences and has participated on many National Research Council committees, including the Committee on Review of the U.S. DRIVE Research Program, Phase 4 and the Committee on Review of the FreedomCAR and Fuel Research Program, Phase 3. He has a BS from Calvin College and an MS and a PhD in physics from the University of Chicago.

Kelly Sims Gallagher is an associate professor of energy and environmental policy of the Fletcher School, Tufts University. She directs the Energy, Climate, and Innovation research program of the Center for International Environment and Resource Policy. She is also a senior associate and a member of the Board of Directors of the Belfer Center for Science and International Affairs of Harvard University, where she previously directed the Energy Technology Innovation Policy research group. Broadly, she focuses on energy and climate policy in the United States and China. She is particularly interested in the role of policy in spurring the development and deployment of cleaner and more efficient energy technologies domestically and internationally. She speaks Spanish and basic Mandarin Chinese and is a member of the Council on Foreign Relations. She is the author of *China Shifts Gears: Automakers, Oil, Pollution, and Development* (MIT Press, 2006), editor of *Acting in Time on Energy Policy* (Brookings Institution Press, 2009), and author of numerous academic articles and policy reports. A Truman Scholar, she has a Master of Arts in Law and Diplomacy and a PhD in international affairs from the Fletcher School and an AB from Occidental College.

Roland Hwang is the transportation program director for the Natural Resources Defense Council (NRDC) and works on sustainable-transportation policies. He is an expert on clean vehicle and fuels technologies and was a member of the Technology Assessment and Economic Panel of the Intergovernmental Panel on Climate Change, which won the 2007 Nobel Peace Prize. Mr. Hwang serves or has served on numerous advisory panels, including the California Plug-in Electric Vehicle Collaborative, the National Academy of Sciences Committee on Fuel Economy, the U.S. EPA Mobile Source Technical Review Subcommittee, the California Air Resources Board's Alternative and Renewable Fuels and Vehicles program, the California Hydrogen Highway Network Advisory Panel, the Automotive X Prize, and the Western Governors' Association Transportation Fuels for the Future Initiative. Before joining NRDC, he was the director of the Union of Concerned Scientists transportation program. He has also worked for the U.S. Department of Energy at Lawrence Berkeley National Laboratory and the California Air Resources Board as an air-pollution engineer and was involved in forecasting residential and industrial energy demand, permitting of hazardous-waste incinerators, and evaluating toxic air emissions from landfills. He is currently on the National Research Council Committee on Fuel Economy of Light-Duty Vehicles, Phase 2. Mr. Hwang has an MS in mechanical engineering from the University of California, Davis and a master's degree in public policy from the University of California, Berkeley.

Peter Isard is a consultant on economic policy issues and has held various managerial positions with the International Monetary Fund (IMF) during 1985–2008, primarily in the Research Department. Dr. Isard played a lead role in helping Lithuania design an economic transformation program during 1991–1992 and spent the 2002–2003 academic year at the University of Maryland. He retired in June 2008 as deputy director of the IMF Institute, the department that provides training on economic policy-making for member-country officials. Before joining the IMF in 1985, he spent 1970 in the Research Department of the IMF, taught at Washington University in St. Louis during 1971–1972, held research and management positions at the Federal Reserve Board during 1972–1985, and spent a year during 1979–1980 at the Bank for International Settlements. Dr. Isard is the author of numerous articles in academic journals, primarily on exchange rates and monetary policy strategies. He is also the author of two books—*Exchange Rate Economics* (1995) and *Globalization and the International Financial System* (2005)—and editor of several others. He has an undergraduate degree in mathematics from the Massachusetts Institute of Technology and a PhD in economics from Stanford University.

Linos Jacovides is President of Paphos Consulting and an adjunct professor of electrical and computer engineering at Michigan State University. He retired as director of Delphi Research Laboratories, a position he held from 1998 to 2007. Dr. Jacovides joined General Motors Research and Development in 1967 and became department head of electrical engineering in 1985. His research was in the interactions between power electronics and electric machines in electric vehicles and locomotives. He later transitioned to Delphi with a group of researchers from General Motors to set up the Delphi Research Laboratories. He is a member of the National Academy of Engineering and has served on numerous National Research Council committees, including the National Cooperative Highway Research Program Project Panel on Effects of Changing Transportation Energy Supplies and Alternative Fuel Sources on State Departments of Transportation, the Committees on Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy (Phases 1 and 2), the Committee on Review of the U.S. Drive Research Program Phase 4, the Committee on Electric Vehicle Controls and Unintended Acceleration, and the Committee on Review of the FreedomCAR and Fuel Research Program, Phase 3. Dr. Jacovides is a fellow of IEEE and SAE International and served as president of the Industry Applications Society of IEEE in 1990. He received a BS in electrical engineering and an MS in machine theory from the University of Glasgow, Scotland, and his PhD in generator control systems from the Imperial College, University of London.

Ulric Kwan is the manager of electric vehicles at Pacific Gas and Electric (PG&E). He oversees policy, strategy, and engagement in this field. Mr. Kwan is also one of the leaders for PG&E in demand-side management, the use of the demand side in wholesale markets, and transmission and distribution applications. Before PG&E, Ulric worked at Siemens as an energy engineer and with LCG Consulting as a wholesale-market consultant. Mr. Kwan has a bachelor's and master's degrees in mechanical engineering from the University of Calgary and Stanford University, respectively.

Rebecca Lindland is a private consultant. She was formerly the director of research for IHS Automotive, where she was responsible for evaluating and assessing automobile manufacturers that participate in U.S. and Canadian marketplaces. She has a particular interest in how manufacturers' decisions reflect consumer values. While at IHS Automotive, she was often quoted in the news media—including the *New York Times*, *Business Week*, *Reuters*, *Bloomberg News*, the *Los Angeles Times*, the *Detroit News*, the *Detroit Free Press*, the *Wall Street Journal*, and *National Public Radio*—for her coverage of new-product launches and the balance-sheet conditions of manufacturers and brands. Before her work at IHS, Ms. Lindland worked at AlliedSignal in Rumford, RI, where she forecasted such products as Bendix brakes. A life-long automotive enthusiast, she began her career as a staff accountant with Mercedes-Benz Credit Corporation in Norwalk, CN. She is a former board member of the Society of Automotive Analysts, the International Motor Press Association, and the Motor Press Guild and was accepted into Strathmore's 2001 *Who's Who in American Business*. She is on the National Research Council Committee on Fuel Economy of Light-Duty Vehicles, Phase 2. Ms. Lindland holds a double major in accounting and business administration from Gordon College, Wenham, MA.

Ralph D. Masiello is the senior vice president and innovation director of KEMA, Inc. In recent years, his focus has been on electric market and transmission operator business models and systems, including cost-benefit analyses of paradigms for models, systems, and operations. He has also developed technology and strategic plans for market operators and automation and smart grid roadmaps for several independent system operators. His current interests include the market and utility applications of advanced storage devices for ancillary markets, reliability, and energy economics; the grid integration of electric vehicles; and the development of advanced building-to-grid concepts. He has provided expert testimony before Congress on metering systems and market operations and cosigned a Supreme Court amicus curiae brief on transmission access and native load service. He was recently appointed to the Department of Energy Electricity Advisory Council. Dr. Masiello is a fellow of the IEEE and has served as chairman of Power System Engineering, as chairman of Power Industry Computing Applications, on the Editorial board of *IEEE Proceedings* and on the advisory board of *IEEE Spectrum* magazine. He is the winner of the 2009 IEEE PES Concordia award for power system analysis and is a member of the National Academy of Engineers. He received his PhD from the Massachusetts Institute of Technology in electrical engineering.

Jakki Mohr is the Regents Professor of Marketing at the University of Montana–Missoula (UM). An international expert and innovator in marketing of high-technology products and services, she has achieved international acclaim for *Marketing of High-Technology Products and Innovations* (coauthor with S. Sengupta and S. Slater, with European and India/SE Asia editions and translations in Chinese, Portuguese, and Korean). Motivated by the desire to apply the promise of new technologies to solve social and global problems, Dr. Mohr has provided training to companies and universities worldwide in strategic market planning to commercialize innovation. She has received numerous teaching awards—including the Outstanding Marketing Teacher Award (presented by the Academy of Marketing Science), the Carnegie Foundation CASE Professor of the Year, and the Most Inspirational Teacher of the Year Award at the University of Montana—and the Distinguished Scholar Award, the John Ruffatto Memorial Award, and the Dennison Presidential Faculty Award for Distinguished Accomplishment. Dr. Mohr served as a Fulbright senior specialist in Montevideo, Uruguay. Her research has received national awards and has been published in the *Journal of Marketing*, the *Strategic Management Journal*, the *Journal of the Academy of Marketing Science*, the *Journal of Public Policy and Marketing*, and others. In research sponsored by the Marketing Science Institute, she studies how companies use biomimicry (innovations inspired by nature that are based on underlying biologic mechanisms) to solve technical and engineering challenges, the basis of her TEDxSanDiego talk in 2011. Before joining UM in fall 1997, Dr. Mohr was an assistant professor at the University of Colorado Boulder (1989–1997). Before beginning her academic career, she worked in Silicon Valley in advertising for Hewlett-Packard's Personal Computer Group and TeleVideo Systems. Dr. Mohr received her PhD from University of Wisconsin–Madison.

Melissa Schilling is a professor of management and organizations at New York University Stern School of Business. Dr. Schilling teaches strategic management, corporate strategy, and technology and innovation management. She is widely recognized as an expert in innovation and strategy in high-technology industries. Her textbook, *Strategic Management of Technological Innovation* (now in its fourth edition), is the top innovation-strategy text in the world and is available in seven languages. Her research in innovation and strategy has earned her such awards as the National Science Foundation's

CAREER Award and the Best Paper in Management Science and Organization Science for 2007 Award. Her research has appeared in leading academic journals, such as the *Academy of Management Journal*, the *Academy of Management Review*, *Management Science*, *Organization Science*, the *Strategic Management Journal*, and the *Journal of Economics and Management Strategy and Research Policy*. She sits on the editorial review boards of *Organization Science* and *Strategic Organization*. Dr. Schilling received her BS in business administration from the University of Colorado Boulder and her PhD in strategic management from the University of Washington.

Richard Tabors is president of Across the Charles and is director of the Utility of the Future Project at the MIT Energy Initiative. Until July 2012, he was vice president of Charles River Associates (CRA) in the Energy & Environment Practice. He founded the engineering-economics consulting firm of Tabors Caramanis & Associates (TCA) in 1989 to provide economic, regulatory, and financial analytic support to the restructuring of the U.S. and international electric-power industry. TCA was sold to CRA in 2004. He was a researcher and member of the faculty at Harvard University from 1970 to 1976 and was at Massachusetts Institute of Technology as a senior lecturer in technology management and policy and a research director in power systems from 1976 to 2004. He is a visiting professor of electrical engineering at the University of Strathclyde in Glasgow, Scotland. His research and development activities at MIT led to his being the author or a coauthor of over 80 articles and books, including *Spot Pricing of Electricity,* on which the economic restructuring of the electric-utility wholesale and retail markets is based. Dr. Tabors continues his work directing and consulting activities in regulation, litigation, and asset evaluation in the power industry with a focus on development of future platforms and pricing structure of the "smart grid." He received a BA in biology from Dartmouth and an MS and a PhD from the Maxwell School of Syracuse University in geography and economics.

Tom Turrentine is director of the California Energy Commission's Plug-in Hybrid & Electric Vehicle Research Center at the Institute of Transportation Studies, University of California, Davis. For the last 20 years, Dr. Turrentine has been researching consumer response to alternative fuels, vehicle technologies, road systems, and policies that have environmental benefits. His most recent work includes multiyear projects to study consumer use of plug-in electric vehicles, including the BMW Mini E, PRIUS PHEV conversions, the Nissan Leaf, GM Volt, PHEV pickups, and specially designed energy-feedback displays in vehicles. He and his researchers are studying EV and PHEV driver travel patterns and use of infrastructure and are developing planning tools to advise on deployment of infrastructure and optimal ways to integrate plug-in vehicles into California's grid. He and his team wrote "Taking Charge," a plan for California to develop a PEV market, which is the blueprint for the California PEV Collaborative. He holds a PhD in anthropology.

Appendix B

Statement of Task

An ad hoc committee will conduct a study identifying the market barriers slowing the purchase of electric vehicles (EVs, which for this study include pure battery electric vehicles [BEVs] and plug-in hybrid electric vehicles [PHEVs]) and hindering the deployment of supporting infrastructure in the United States. The study will draw on input from state utility commissions, electric utilities, automotive manufacturers and suppliers, local and state governments, the Federal Energy Regulatory Commission, federal agencies, and others, including previous studies performed for the Department of Energy (DOE), to help identify barriers to the introduction of electric vehicles, particularly the barriers to the deployment of the necessary vehicle charging infrastructure, and recommend ways to mitigate these barriers. The study will focus on light-duty vehicles but also draw upon experiences with EVs in the medium- and heavy-duty vehicle market segment. Specifically, the committee will:

1. Examine the characteristics and capabilities of BEV and PHEV technologies, such as cost, performance, range, safety, and durability, and assess how these factors might create barriers to widespread deployment of EVs. Included in the examination of EV technologies will be the characteristics and capabilities of vehicle charging technologies.
2. Assess consumer behaviors and attitudes towards EVs and how these might affect the introduction and use of EVs. This assessment would include analysis of the possible manner by which consumers might recharge their vehicles (vehicle charging behaviors, e.g., at home, work, overnight, frequency of charging, time of day pricing, during peak demand times, etc.) and how consumer perceptions of EV characteristics will impact their deployment and use.
3. Review alternative scenarios and options for deployment of the electric vehicle infrastructure, including the various policies, including tax incentives, and business models necessary for deploying and maintaining this infrastructure and necessary funding mechanisms. The review should include an evaluation of the successes, failures, and lessons learned from EV deployment occurring both within and outside the United States.
4. Examine the results of prior (and current) incentive programs, both financial and other, to promote other initially uneconomic technologies, such as flex-fuel vehicles, hybrid electric vehicles, and now PHEVs/BEVs to derive any lessons learned.
5. Identify the infrastructure needs for the electricity sector, particularly the needs for an extensive electricity charging network, the approximate costs of such an infrastructure, and how utility investment decision making will play into the establishment of a charging network. As part of this assessment, the committee will identify the improvements in the electricity distribution systems needed to manage vehicle charging, minimize current variability, and maintain power quality in the local distribution network. Also, the committee will consider the potential impacts on the electricity system as a whole, potentially including: impacts on the transmission system; dispatch of electricity generation plants; improvements in system operation and load forecasting; and use of EVs as grid-integrated electricity storage devices.

6. Identify the infrastructure needs beyond those related to the electricity sector. This includes the needs related to dealer service departments, independent repair and maintenance shops, battery recycling networks, and emergency responders.
7. Discuss how different infrastructure deployment strategies and scenarios might impact the costs and barriers. This might include looking at the impacts of focusing the infrastructure deployment on meeting the needs for EVs in vehicle fleets, where the centralization of the vehicle servicing might reduce the costs for deploying charging infrastructure or reduce maintenance issues, or focusing the infrastructure deployment on meeting the needs for EVs in multi-family buildings and other high-density locations, where daily driving patterns may be better suited to EV use than longer commutes from single family homes in lower density areas. This might also include looking to the extent possible of how the barriers and strategies for overcoming barriers may differ in different U.S. localities, states, or regions.
8. Identify whether there are other barriers to the widespread adoption of EVs, including shortages of critical materials, and provide guidance on the ranking of all barriers to EV deployment to help prioritize efforts to overcome such barriers.
9. Recommend what roles (if any) should be played by the federal government to mitigate those market barriers and consider what federal agencies, including the DOE, would be most effective in those roles.
10. Identify how the DOE can best utilize the data on electric vehicle usage already being collected by the department.

The committee's analysis and methodologies will be documented in two NRC-approved reports. The study will consider the technological, infrastructure, and behavioral aspects of introducing more electric vehicles into the transportation system. A short interim report will address, based on presentations to the committee and the existing literature, the following issues:

1. The infrastructure needs for electric vehicles;
2. The barriers to deploying that infrastructure; and
3. Optional roles for the federal government to overcome these barriers, along with initial discussion of the pros and cons of these options.

The final report will discuss and analyze these issues in more detail and present recommendations on the full range of tasks listed in Items (1) to (10) for the full study. The final report will include consideration of the infrastructure requirements and barriers as well as technological, behavioral, economic, and any other barriers that may slow the deployment of electric vehicles, as well as recommendations for mitigating the identified market barriers. It is envisioned that the committee will hold meetings in different locations around the United States, as well as collect information on experiences in other countries, in order to collect information on different approaches being taken to overcoming the barriers to electric vehicle deployment and its supporting charging infrastructure.

Appendix C

Meetings and Presentations

FIRST COMMITTEE MEETING
OCTOBER 28–29, 2012

EV Everywhere: Overview and Status
Patrick B. Davis, Program Manager, Vehicle Technologies Program, U.S. Department of Energy

EV Everywhere Grand Challenge: Charging Infrastructure Enabling Flexible EV Design
Lee Slezak, Technology Manager, Vehicle Systems, Vehicle Technologies Program, U.S. Department of Energy

DOE AVTA: The EV Project and Other Light-Duty Electric Drive Vehicle Activities
James Francfort, Principal Investigator, Advanced Vehicle Testing Activity, Idaho National Laboratory

SECOND COMMITTEE MEETING
DECEMBER 17–19, 2012

Charging Infrastructure Needs
Marcus Alexander, Manager, Vehicle Systems Analysis, Electric Power Research Institute

Presentation
Britta K. Gross, Director, Advanced Vehicle Commercialization Policy, General Motors

Overcoming Barriers to Deployment of Electric Vehicles
Mike Tamor, Executive Technical Leader, Energy Systems and Sustainability, Ford Motor Company

Overcoming Barriers to Electric Vehicle Deployment: Barriers to Deployment, an OEM Perspective
Joseph Thompson, Nissan

The Electrification Coalition: Revolutionizing Transportation and Achieving Energy Security
Jonna Hamilton, Vice President for Policy, Electrification Coalition

Electric Vehicle Charging Services
Richard Lowenthal, Founder and CTO, ChargePoint

The Complete Electric Vehicle Charging Solution
Michael Krauthamer, Director, Mid-Atlantic Region, eVgo

Presentation
Jason Wolf, Vice President for North America, Better Place

The DOE Vehicle Technologies Analysis Toolbox and EV Everywhere Target-Setting
Jacob Ward, Vehicle Technologies Analysis Manager, U.S. DOE

The Need for Public Investments to Support the Plug-in Electric Vehicle Market
Nick Nigro, Manager, Transportation Initiatives, Center for Climate and Energy Solutions

Research Insights from the Nation's Highest Residential Concentration of Electric Vehicles
Brewster McCracken, President and CEO, Pecan Street Inc.

Electric Vehicle Initiatives in the Houston–Galveston Region
Allison Carr, Air Quality Planner, Houston-Galveston Area Clean Cities Coalition

The EV Project Deployment Barriers
Donald Karner, ECOtality North America

New Models of Mobility and EV Deployment
Jack Hidary, Global EV Leader, Hertz

Electric Vehicle Infrastructure Demonstration Projects: Lessons Learned
Rick Durst, Transportation Electrification Project Manager, Portland General Electric

THIRD COMMITTEE MEETING
JANUARY 25–26, 2013

No open-session presentations were held during this meeting.

Appendix D

Technical Specifications

Spurred initially by a California mandate, automakers have agreed on connectors and standards for 120-V and 240-V alternating current (ac) charging (see Figure D-1). Most plug-in electric vehicles (PEVs) can thus be charged with chargers made by a variety of manufacturers. Such cooperation and interchangeability remove what otherwise could be a substantial barrier to the adoption of PEVs.

That is not the case for direct current (dc) fast charging. There are now at least two competing standards for the fast charge. Most battery electric vehicles (BEVs) on the road that can be fast-charged and the vast majority of chargers that have been installed in the United States, Japan, and Europe use the CHAdeMO standard (see Figure D-2). Automobile manufacturers that intend to introduce PEVs starting in 2013 and SAE International have agreed on a new standard that they wish to call the Universal EV Combined Charging System (see Figure D-3). Furthermore, Tesla has unveiled several DC fast-charging stations in California and on the East Coast that use a different plug design (see Figure D-4). To help to develop standard terminology and technical specifications, SAE International has developed the charging specifications and terminology shown in Figure D-5. The standard accommodates two power levels for DC fast charging: Level 1 at a maximum power of 40 kW and Level 2 at a maximum power of 100 kW.

FIGURE D-1 The standard connector used for AC Level 1 and Level 2 charging (the J1772 standard of SAE International) allows most PEVs to be charged with chargers built by various manufacturers. SOURCE: Adapted from GM, 2012.

FIGURE D-2 The CHAdeMO plug for DC fast charging is used for most DC fast chargers now available in the United States, Europe, and Japan and is available on most BEVs that can accept DC fast charging. SOURCE: Brissette, 2013.

PREPUBLICATION DRAFT—Subject to Further Editorial Correction

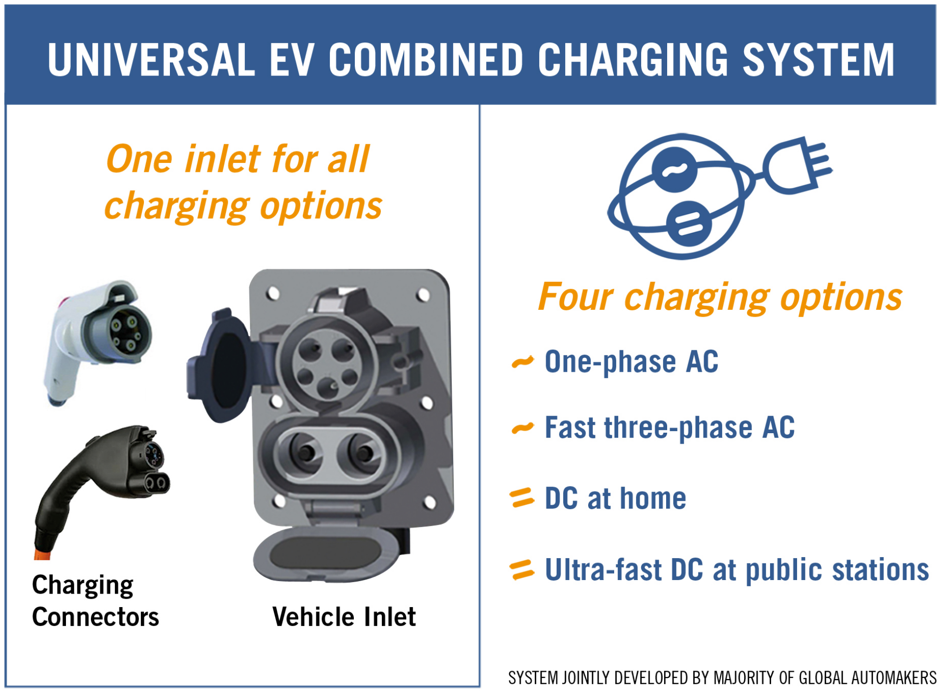

FIGURE D-3 Standard proposed as an alternative to the CHAdeMO connector includes the current plug and socket for AC Level 1 and 2 charging as the upper connector and two lower connectors added for DC fast charging. SOURCE: GM, 2012.

Permission pending

FIGURE D-4 The Tesla proprietary plug for DC fast charging is used for all Tesla DC fast chargers (Superchargers) now available in the United States. It is available only on the Tesla Model S. SOURCE: Gordon-Bloomfield, 2011.

SAE Charging Configurations and Ratings Terminology

SAE International

	AC level 1 (SAE J1772™) PEV includes on-board charger 120V, 1.4 kW @ 12 amp 120V, 1.9 kW @ 16 amp Est. charge time: PHEV: 7hrs (SOC* - 0% to full) BEV: 17hrs (SOC – 20% to full)		**DC Level 1** (SAE J1772™) EVSE includes an off-board charger 200-500 V DC, up to 40 kW (80 A) Est. charge time (20 kW off-board charger): PHEV: 22 min. (SOC* - 0% to 80%) BEV: 1.2 hrs. (SOC – 20% to 100%)
	AC level 2 (SAE J1772™) PEV includes on-board charger (see below for different types) 240 V, up to 19.2 kW (80 A) Est. charge time for 3.3 kW on-board charger PEV: 3 hrs (SOC* - 0% to full) BEV: 7 hrs (SOC – 20% to full) Est. charge time for 7 kW on-board charger PEV: 1.5 hrs (SOC* - 0% to full) BEV: 3.5 hrs (SOC – 20% to full) Est. charge time for 20 kW on-board charger PEV: 22 min. (SOC* - 0% to full) BEV: 1.2 hrs (SOC – 20% to full)		**DC Level 2** (SAE J1772™) EVSE includes an off-board charger 200-500 V DC, up to 100 kW (200 A) Est. charge time (45 kW off-board charger): PHEV: 10 min. (SOC - 0% to 80%) BEV: 20 min. (SOC – 20% to 80%)

Voltages are nominal configuration voltages, not coupler ratings
Rated Power is at nominal configuration operating voltage and coupler rated current
Ideal charge times assume 90% efficient chargers, 150W to 12V loads and no balancing of Traction Battery Pack

Notes:
1) BEV (25 kWh usable pack size) charging always starts at 20% SOC, faster than a 1C rate (total capacity charged in one hour) will also stop at 80% SOC instead of 100%
2) PHEV can start from 0% SOC since the hybrid mode is available.

ver. 100312

FIGURE D-5 Society of Automotive Engineers charging configurations and ratings terminology. SOURCE: SAE, 2012.

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