Plug-In Electric Vehicles: Challenges and Opportunities

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June 2013
Report Number T133

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Acknowledgments

This work was funded by the Energy Foundation, the Kresge Foundation, the Tilia Fund, and a foundation that wishes to remain anonymous. We very much appreciate their support.

The authors thank Luke Tonachel and Max Baumhefner of Natural Resources Defense Council (NRDC), William Chernicoff of Toyota Motor North America Inc., Jack Deppe of Deppe Consulting LLC, and Robert Ozar of Michigan Public Service Commission for reviewing this report. Karin Matchett provided valuable editorial advice. Any remaining errors are the sole responsibility of the authors.

Several ACEEE staff including Steven Nadel, Neal Elliott, Glee Murray, and Therese Langer provided reviews and valuable comments at various stages in the development of this work, which the authors greatly appreciate. Thanks also to Patrick Kiker and Renee Nida of ACEEE's Communications staff.

Executive Summary

Plug-in electric vehicles (PEVs) present an alternative vehicle technology to a market long monopolized by petroleum-fueled vehicles. Large-scale introduction of PEVs into the light-duty fleet would substantially reduce U.S. oil consumption. It could also deliver important environmental benefits—specifically reduced emissions of greenhouse gases (GHG) and other pollutants—but these benefits will vary with the source of the electricity used to charge the PEVs. On the average U.S. electricity generation mix and on a full-fuel-cycle basis, PEVs today offer major reductions in GHG emissions relative to conventional gasoline-powered vehicles and modest reductions over hybrids, while PEVs' criteria pollutant emissions are typically somewhat higher than those of gasoline vehicles. GHG and criteria emissions associated with both vehicle types will decline in the coming years due to federal regulations, among other factors. In the longer term, however, meeting transportation sector climate goals will require vehicles that run on low-carbon fuels, such as PEVs running on electricity generated from renewable sources. There are therefore strong environmental and economic reasons to encourage a substantial presence of PEVs in the U.S. vehicle fleet.

A wealth of policies and programs are in place to support PEV adoption, including federal, state, and local government measures; activities in the private sector; and activities undertaken by utilities and utility regulators to prepare for and promote PEV adoption. At the federal level, notable policies include a $7,500 consumer tax credit for PEV purchase, grants and loans to automobile manufacturers and suppliers for the development of advanced vehicles and batteries, and funding for consumer education and PEV deployment in communities. Recently adopted federal GHG and fuel economy rules also strongly incentivize the production of PEVs by virtue of these vehicles' value in helping manufacturers comply with the new standards. At the state level, California has led the way in promoting PEVs and other advanced vehicles with a wide array of policies including its Zero-Emission Vehicle Program, the Low Carbon Fuel Standard, and incentive programs aimed at consumers, manufacturers, and infrastructure providers. A limited number of municipalities, including Los Angeles, New York, and Portland, have also taken steps to promote PEV adoption, such as investing in public charging infrastructure, ensuring favorable electricity rates for PEV charging, and purchasing PEVs for the city fleet.

However, while a great number and variety of PEV policies are in place, these policies are not yet sufficiently comprehensive or coordinated to achieve widespread adoption of PEVs in the immediate future. Moreover, current policies are not in all cases crafted to best achieve the benefits that PEVs can bring. Significant challenges stand in the way of widespread PEV adoption, including the high cost and performance limitations of batteries, short vehicle driving range, limited availability and convenience of vehicle charging, and an insufficient variety of PEV models to cover the vehicle market.

On the utility side, while PEV charging will not represent a major draw on electricity supplies overall in the short or medium term and would tend to improve utility load factor in off-peak periods, localized power disruptions could occur in neighborhoods with high PEV adoption due to overloading of distribution transformers. In addition, utilities will need to determine how to set tariffs that simultaneously accomplish three objectives: (1) be attractive enough to encourage PEV adoption;

(2) be effective at managing the timing of vehicle charging; and (3) be "fair" in the sense of not resulting in unjustified cross-subsidies from other ratepayers. Well-designed policies are called for to overcome these challenges and maximize the benefits that PEVs offer.

Additional policies could accelerate the penetration of PEVs in the U.S. vehicle fleet. ACEEE recommends the following actions on the part of the federal government:

- *Support further performance improvement and cost reduction for batteries*—Focus battery R&D on cost reduction, longevity, and higher energy density, including new battery chemistries.
- *Set policies to help increase PEV sales volumes*—Maintain steady ramp-up of fuel economy standards; consider adopting a revenue-neutral feebate program for vehicles, based on fuel economy or greenhouse gas emissions performance; increase PEV purchases for federal fleets.
- *Help to improve the charging experience*—Promote standardization of charging protocols; reinstate tax incentives for charging station installation; expand pilot programs for PEV deployment communities and corridors.

ACEEE recommends that utility regulators:

- *Advance utilities' PEV readiness*—Ensure that utilities are preparing to accommodate increased PEV market penetration, and work with utilities to develop appropriate PEV charging tariffs. Require assessments of charging infrastructure needs and allow cost recovery for utility programs to promote PEV adoption.

Policies to promote PEVs should be designed to ensure these vehicles' continuing improvement and mitigate any adverse impacts they may bring. In particular, GHG standards for vehicles should reflect full-fuel-cycle emissions, so as to promote advances both in PEV efficiency and in clean electricity generation, and taxes on drivers should ensure PEVs pay their fair share, and only their fair share, of highway infrastructure costs. Utility policies should anticipate and address any stresses PEVs may put on the electric grid and electricity ratepayers.

Whether PEVs become the predominant technology in the light-duty vehicle market or fill only certain needs within a diverse market will depend upon factors such as future oil and natural gas prices, advances in conventional vehicle and fuel cell technologies, and breakthroughs in battery technology, as well as future decisions on energy and climate policy. Policies to promote the adoption of PEVs in the U.S. vehicle fleet are warranted, both to develop fuel diversity in the transportation sector and to benefit from, as well as promote, the emergence of a low-carbon electricity grid. With forward-looking policy design, the United States can and should position itself to take full advantage of PEVs' ability to reduce the nation's oil consumption, reduce greenhouse gas and other emissions, and improve the efficiency of the U.S. electricity grid.

Introduction

Internal combustion engine vehicles running on petroleum fuels have dominated the vehicle market for a century. Global demand for petroleum has increased dramatically over that period, and this demand, coupled with geo-political volatility in many oil-producing regions, has resulted in high oil prices and uncertainty in the market. Highway vehicles remain a major source of greenhouse gas (GHG) emissions, as well as substantial local pollutant emissions. In the meantime, availability of new vehicle technologies and non-petroleum fuels is rapidly increasing. These circumstances create a prime opportunity for alternative vehicles, including electric, natural gas, and fuel cell vehicles, to be launched into the market. Such vehicles have the potential not only to reduce U.S. dependence on oil and the trade deficit but also to reduce greenhouse gas emissions.

This report is about plug-in electric vehicles, which include all-electric vehicles, powered solely by batteries, and plug-in hybrid-electric vehicles, powered by both batteries and internal combustion engines. We refer to these vehicle types together as plug-in electric vehicles (PEVs). PEVs do not include hybrid-electric vehicles that cannot be plugged in for recharging. This report presents a broad overview of the PEV landscape, including issues from both the transportation and utility system perspectives. It explores the energy and environmental implications of PEV adoption in the United States and whether and how their use should be promoted.

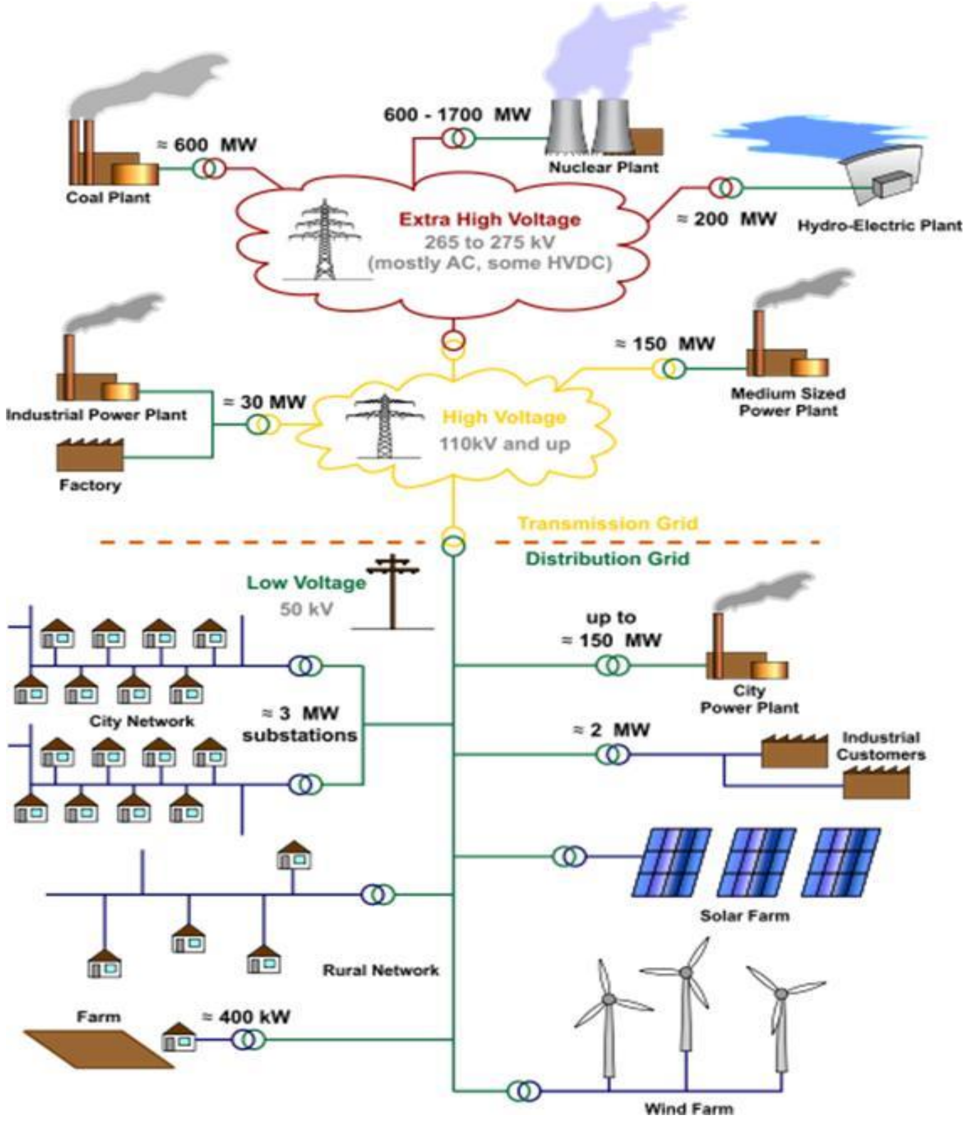
THE ELECTRIC GRID

The U.S. electric utility system is a complex integrated network of electricity-generating sources (typically power plants), large-capacity transmission lines, and smaller-capacity localized distribution lines and related equipment (Figure1). The amount of electricity generated must be carefully balanced with the amount of customer demand at any given time, because of the inability—currently—of the grid to cost-effectively store electricity in large quantities. The electricity system balances electricity generation with consumer demand by having a suite of generating plants of different types that allow that system to match generation to load in real time. The use of PEVs can affect the grid in two ways. Their existence, especially as they are adopted in greater and greater numbers, means an increasing load on the grid. But they stand to contribute to grid stability as well in several respects, as discussed below.

Baseload generating facilities are designed to operate continuously and have the lowest operating costs. These large generating plants are most often coal or nuclear plants (or in some regions, large dams for generating hydropower). Peaking plants operate during a relatively small number of hours per year, when electricity demand is the highest, and they have relatively high operating costs. A variety of intermediate generating facilities operate less than baseload plants, but more than peaking plants, and typically use fossil fuels of some type (most commonly, natural gas). Finally, there are increasing amounts of renewable energy generating sources, primarily wind and some solar. These sources are intermittent, as they are only available while the wind blows or the sun shines.

The mix of generating sources that contribute to the power delivered by the electricity grid varies significantly from region to region, depending upon local resource availability and costs, and state and regional energy policies.[1] One of the characteristics of our grid, and a relatively new one, is that it relies on multiple energy sources: hydro, nuclear, coal, gas, etc. That was not the case 50 years ago. Having multiple fuel sources increases flexibility and provides a measure of protection against fuel supply disruptions and price spikes. Unlike the grid, our transportation system is almost entirely dependent upon petroleum fuels.

Figure 1: The Electricity Generation and Distribution System



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[1] Energy efficiency programs are also increasingly being used as a utility system resource (see York et al. 2012). Rather than inputting electricity into the grid, these energy efficiency programs reduce customer demand, thereby reducing the amount of electricity generation needed.

Well-to-Wheels Efficiency

To a large extent, a vehicle's energy efficiency and the characteristics of the fuels used to power it determine the environmental impacts and operating costs of car usage. Vehicle fuel efficiency is typically discussed in terms of miles per gallon (mpg) or, for vehicles running on alternative fuels, miles per gallon of gasoline equivalent (mpg). Here, a gallon gasoline equivalent is the amount of an alternative fuel such as electricity or natural gas having the same energy content (in joules, for example) as one gallon of gasoline. Table 1 shows the fuel economy and annual fuel consumption of five model year 2013 compact cars, two gasoline-powered and two PEVs. The gasoline-powered vehicles are a Ford Focus FWD (front-wheel drive) with automatic transmission and the Toyota Prius C hybrid, and the PEVs are the Chevy Volt plug-in hybrid and the Ford Focus Electric.

Table 1: Fuel Economy and Energy Consumption of Five Model Year 2013 Vehicles

	Fuel Economy (DOE and EPA 2013)	Annual Fuel Consumption (gasoline gallons equivalent)*
Ford Focus FWD 2.0L automatic (conventional gasoline)	31 mpg	387
Toyota Prius C (hybrid electric)	50 mpg	240
Chevrolet Volt (plug-in hybrid-electric)	98 mpg (running on electricity) 37 mpg (running on gasoline)	205**
Ford Focus Electric (all-electric)	105 mpg	114
Honda Civic Natural Gas	31 mpg	387

* Assumes 12,000 miles driven per year

** Assumes 60% of miles driven on electricity, based on the Volt's 38-mile "all-electric range"

The PEVs clearly outperform the gasoline-powered vehicles by this measure, largely because an electric vehicle motor is far more energy-efficient than an internal combustion engine. On the other hand, a great deal of energy is lost during the generation, transmission and distribution of the electricity that powers it. A more comprehensive comparison the various vehicle types from an energy efficiency perspective must be a "well-to-wheels" comparison, which encompasses the fuel production and delivery stages as well as the fuel use stage.

In a vehicle with an internal combustion engine, the wheels are turned by a drivetrain, which is driven by the conversion of chemical energy into kinetic energy. In this case the chemical energy comes in the form of gasoline or diesel fuel, whose combustion occurs in the engine. In an electric vehicle the wheels are turned by a drivetrain that is also driven by the conversion of chemical energy into kinetic energy—but in this case the chemical energy is stored in the battery. Its source (if the vehicle was charged with grid electricity) is also likely to be combustion, specifically the combustion of coal or natural gas at a central power plant. The battery's chemical energy may also come from nuclear and renewable sources, depending on the fuel mix of the power plant.

To compare well-to-wheels efficiencies of gasoline-powered vehicles and PEVs, we calculate well-to-wheels efficiency for each vehicle type as the product of well-to-tank and tank-to-wheel efficiencies. The well-to-tank energy efficiency, also known as fuel production efficiency, encompasses the efficiencies of stages from fuel extraction to delivery of fuel to the point at which it is ready to be used in the vehicle. Well-to-tank energy efficiency of an all-electric vehicle is calculated by multiplying the efficiencies of power generation, power distribution, and battery charging. Table 2 shows the share of power generation and average plant efficiency by energy source in the United States in 2012 (EIA 2012a, 2012b, 2013a). These average efficiencies range from 32 to 42%, and the overall average efficiency of electricity generation in the United States in 2012 was 36%. The efficiency of electricity transmission and distribution is in the range of 93 to 94% (EIA 2009, 2012b). The charging efficiency of batteries in electric vehicles is 90 to 94% (DOE and EPA 2013; Thomas 2009). Thus, the well-to-tank efficiency of an all-electric vehicle charged on the average U.S. electricity mix is approximately 30–32%. It is important to note that generation mix varies widely both by location and by time of day, however.

Table 2: 2012 Average U.S. Electricity Generation Share and Generation Efficiency by Energy Source

	Coal	Petroleum	Natural Gas	Nuclear	Renewables & Others	Total
Share of Generation	37%	1%	31%	19%	12%	100%
Generation Efficiency*	33%	32%	42%	33%	35%	36%

* Generation efficiency is calculated from the average heat rate (Btus per kilowatt hour) of these power plants per EIA (2012c).

Tank-to-wheels efficiency encompasses the efficiency with which energy is delivered to the wheels to propel the vehicle. Battery energy conversion efficiency in PEVs is approximately 90%, while electric motors used in these vehicles are typically 76 to 80% efficient (DOE and EPA 2013; Thomas 2009). The high battery and motor efficiencies, together with efficient drivetrain systems, result in tank-to-wheel efficiencies in the range of 64 to 68% for all-electric vehicles. Taking these ranges for well-to-tank and tank-to-wheels efficiency together gives a well-to-wheels efficiency of 19 to 22% for today's all-electric vehicle on the average power generation mix.

Production of petroleum fuels involves much smaller energy losses. Gasoline typically has a well-to-tank efficiency of about 88% (Wang 2008). Gasoline-powered vehicles' tank-to-wheels efficiencies are far lower than those of all-electric vehicles, however, because of the low thermal efficiency of internal combustion engines. The thermal efficiency of gasoline engines used in today's light-duty vehicles ranges from 30 to 35% (Edwards et al. 2011). Average tank-to-wheels efficiency for 2011 gasoline-powered vehicles with standard and advanced engines were 14% and 18%, respectively, while the average 2011 gasoline hybrid-electric vehicles had 24% tank-to-wheels efficiency (Lutsey 2012).

Consequently, well-to-wheels efficiencies of current conventional gasoline-powered vehicles are in the range of 12 to 16%, while a typical hybrid well-to-wheels efficiency is 21%.

Therefore, the well-to-wheels energy efficiency of all-electric vehicles is higher than that of conventional gasoline-powered vehicles, but similar to that of hybrid-electric vehicles. The well-to-tank, tank-to-wheel, and well-to-wheel efficiencies associated with conventional gasoline, hybrid-electric, and all-electric vehicles are summarized in Table 3.

Table 3: Comparison of Current Well-to-Wheels Efficiency by Vehicle Type

	Conventional Gasoline Vehicle	Hybrid-Electric Vehicle	All-Electric Vehicle
Well-to-Tank Efficiency	88%	88%	30–32%
Tank-to-Wheels Efficiency	14–18%	24%	64–68%
Well-to-Wheels (Overall) Efficiency	12–16%	21%	19–22%

Vehicle efficiency will improve in the coming years. For gasoline-powered vehicles, engines and transmissions will improve steadily as part of auto manufacturers' strategies to meet the Corporate Average Fuel Economy (CAFE) and GHG emissions standards recently adopted by the federal government out to model year 2025. The standards will reduce new car fuel consumption by 40% by model year 2025. If we assume that half of that reduction will come from improvements to the engine and transmission (with the remainder coming from vehicle weight reduction, reduction in tire rolling resistance, improvements in vehicle aerodynamics, and the efficiency of vehicle accessories), this will raise the tank-to-wheel efficiency of conventional gasoline-powered vehicles to 18 to 23% and the well-to-wheels efficiency to 15 to 20%. A similar improvement in hybrid-electric vehicles would raise their overall efficiency to about 26%.

Well-to-wheels efficiency will improve for PEVs as well in the near future. The efficiency of electricity generation will increase as coal-fired plants are retired, integrated gasification combined-cycle (IGCC) generation technology becomes more prevalent in coal (and biomass) power plants, and new combined–cycle natural gas plants come on line (ANL 2012). The efficiency of a coal plant using IGCC technology potentially can be boosted to 50% or more (DOE 2013a). General Electric's new combined cycle generation systems offer efficiencies above 60% at high operating loads (GE Energy 2013b) while Siemens' new gas turbine operated in a combined cycle achieved a net efficiency of 60.75% (Siemens 2013). Improvements in transmission and distribution efficiency will also contribute to the overall efficiency of the system. Taken together, these advances will bring generation efficiency to approximately 48% in the next five to ten years, which would bring the well-to-wheel efficiency of all-electric vehicles to 26 to 29%. Improvements in motor efficiency and in battery energy conversion efficiency would raise the efficiency further.

Hence, in terms of well-to-wheels efficiency, PEVs will remain ahead of conventional gasoline-powered vehicles and on par with, or slightly ahead of, non-plug-in hybrids. Energy efficiency does not tell the whole story, however. In the end, it is not energy efficiency per se that will serve as the basis for comparing vehicles, but rather performance in terms of fueling costs and environmental impacts, among other measures. In particular, the GHG emissions associated with the use of either a conventional vehicle or PEV is highly dependent on fuel source and can be lowered dramatically by the use of low-carbon fuels. Charging an all-electric with wind or solar power will eliminate its emissions entirely. Biomass power plants and biofuels also have the potential to reduce GHG emissions, although the full-fuel-cycle impacts of these fuels must be taken into account. In any case, energy efficiency properties are fundamental properties of the vehicle types that then lead to other performance characteristics that more directly influence the market and policy choices. Well-to-wheels efficiency will remain a crucial determinant of fueling costs and the fraction of transportation needs that can be met with low-carbon fuels.

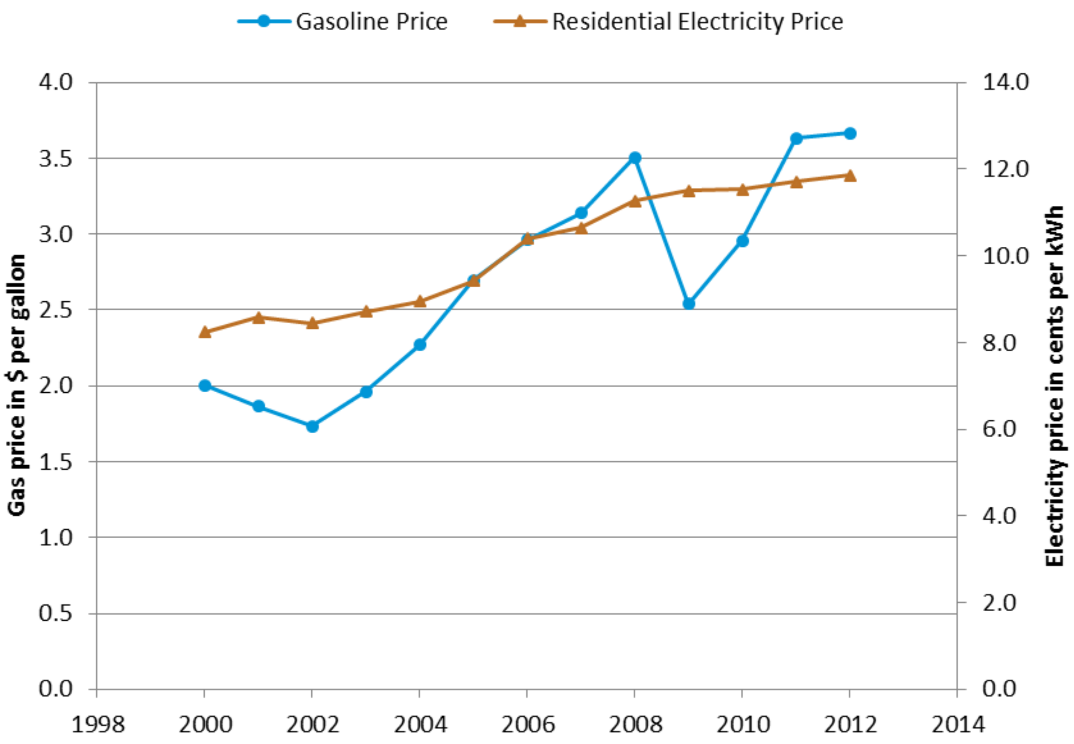
Impacts of Vehicle Electrification

OIL CONSUMPTION

PEVs have the potential to greatly reduce the petroleum dependence of the U.S. transportation sector and the economy as a whole. Highway vehicles are the biggest consumer of oil in the United States, accounting for 62% of total U.S. oil consumption of 18.6 million barrels per day in 2010 (DOE 2012). With substantial penetration into the vehicle market, PEVs could play a big role in reducing overall U.S. oil use. According to a 2013 National Research Council report, a PEV sales share of 35% in 2030 and 80% in 2050 would offset light-duty petroleum consumption by 3.3 million barrels per day in 2030 and 7.4 million barrels in 2050, compared to a “business as usual” scenario with PEV sales remaining below 5% (NRC 2013).

From a consumer perspective, potential benefits of shifting the vehicles away from reliance on petroleum fuels are enormous. The idea of reducing or eliminating trips to the gas station has broad appeal, not only because it means spending less on fuel but because it is convenient and reduces reliance on imported energy. Reduced vulnerability to price spikes is an additional benefit. The price of gasoline has increased by 83% in the last 12 years, while the price of electricity has increased by 43%. Also significant is price volatility. Oil prices have often been volatile since 1960, when the Organization of the Petroleum Exporting Countries (OPEC) was created. While electricity prices have increased gradually in recent years, gasoline prices followed a bumpy path, as shown in Figure 2.

Figure 2: Gasoline and Electricity Price Trends (2000-2012)



Source: EIA 2012d

EMISSIONS

All vehicle types discussed here cause emissions of both GHG and criteria pollutants (pollutants for which the EPA has set National Ambient Air Quality Standards), though emissions associated with the use of all-electric vehicles are purely "upstream" rather than "in-use" emissions. This section considers full-fuel-cycle emissions of the various vehicle types, meaning emissions occurring in the production, transport, and use of the fuel. The quantity of emissions produced by a given vehicle on a full-fuel-cycle basis is determined by a host of factors, but certain emissions characteristics are associated with vehicles of a given type.

Drawing from analysis used to produce new vehicle "green scores" for listings on GreenerCars.org (ACEEE 2013), we compare full-fuel-cycle emissions for the five model year 2013 compact cars shown in Table 1. Emissions are calculated from the vehicles' fuel economy and tailpipe emissions certification, together with properties of the fuels they use (Vaidyanathan and Langer 2011). Table 4 shows each car's annual GHG emissions in metric tons CO_2 equivalent and an annual combined health impact, in dollars, associated with emissions of five criteria pollutants arising from vehicle use: carbon monoxide, hydrocarbons (a criteria pollutant precursor), oxides of nitrogen (NO_x), particulate matter, and sulfur dioxide (SO_x). The health impact is calculated from the pounds of each pollutant emitted, together with a damage cost in dollars per pound for each pollutant and a factor reflecting proximity of emissions to population centers (Vaidyanathan and Langer 2011).

Table 4: Annual Full-Fuel-Cycle Emissions of Five Model Year 2013 Vehicles

	In-Use GHG (metric tons CO_2 equivalent)	Upstream GHG (metric tons CO_2 equivalent)	Total GHG (metric tons CO_2 equivalent)	In-Use Criteria Pollution Health Impact	Upstream Criteria Pollution Health Impact	Total Criteria Pollution Health Impact
Ford Focus FWD	3.6	0.8	4.5	$10.20	$12.73	$22.93
Toyota Prius C	2.4	0.5	3.0	$9.79	$8.35	$18.14
Chevrolet Volt	1.2	2.0	3.2	$3.96	$23.40	$27.36
Ford Focus Electric	0.0	2.5	2.5	$0.00	$27.90	$27.90
Honda Civic Natural Gas	2.8	1.1	3.9	$8.44	$13.36	$21.80

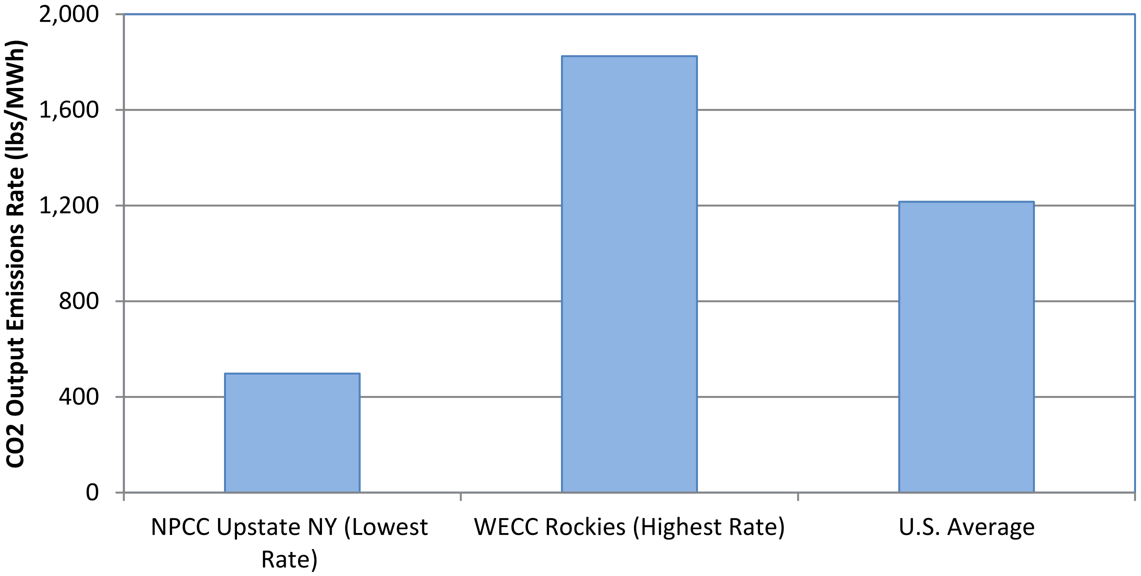
Source: Calculations for GreenerCars.org (ACEEE 2013)

In the case of GHG, Ford Focus Electric emissions are lowest, followed by the Prius C hybrid, the Volt plug-in hybrid, the natural gas Civic, and finally the conventional gasoline-powered Focus, producing nearly twice as much CO_2 as the Focus Electric.

Criteria pollutant emissions follow a different pattern, with the PEVs having the most emissions, the hybrid having the fewest, the natural gas and conventional vehicle falling in between. The spread between highest and lowest emitters is less than in the case of CO_2, however. Also, assigning a moderate cost of $20 per metric ton of CO_{2e} to GHG emissions, the total cost the vehicles impose in GHG emissions is substantially greater than their criteria pollution emissions costs. Finally, it should be noted that, in much of the country, power plant emissions of NO_x and SO_2 are capped and will remain below the cap regardless of how many PEVs are added to the fleet.

Emissions associated with PEV use are highly dependent upon which fuels are used to generate the electricity that charges the battery, and the generation mix varies greatly from region to region. Among the 26 electricity regions used in the federal eGRID database, the (NPCC) Upstate New York zone has the lowest rate of CO_2 emissions per kilowatt-hour, because it has high percentages of hydropower and nuclear power. The Western Electricity Coordinating Council (WECC) Rockies zone, which is highly dependent on coal, has CO_2 emissions rates more than three times higher, as shown in Figure 3 (eGRID 2012). As a result of these variations, driving an all-electric vehicle in upstate New York a will result far lower CO_2 emissions than driving a hybrid-electric vehicle, but the reverse is true in the WECC Rockies zone.

Figure 3: Lowest, Highest and Average Regional CO_2 Emissions Output Rates from Electricity Generation in 2009

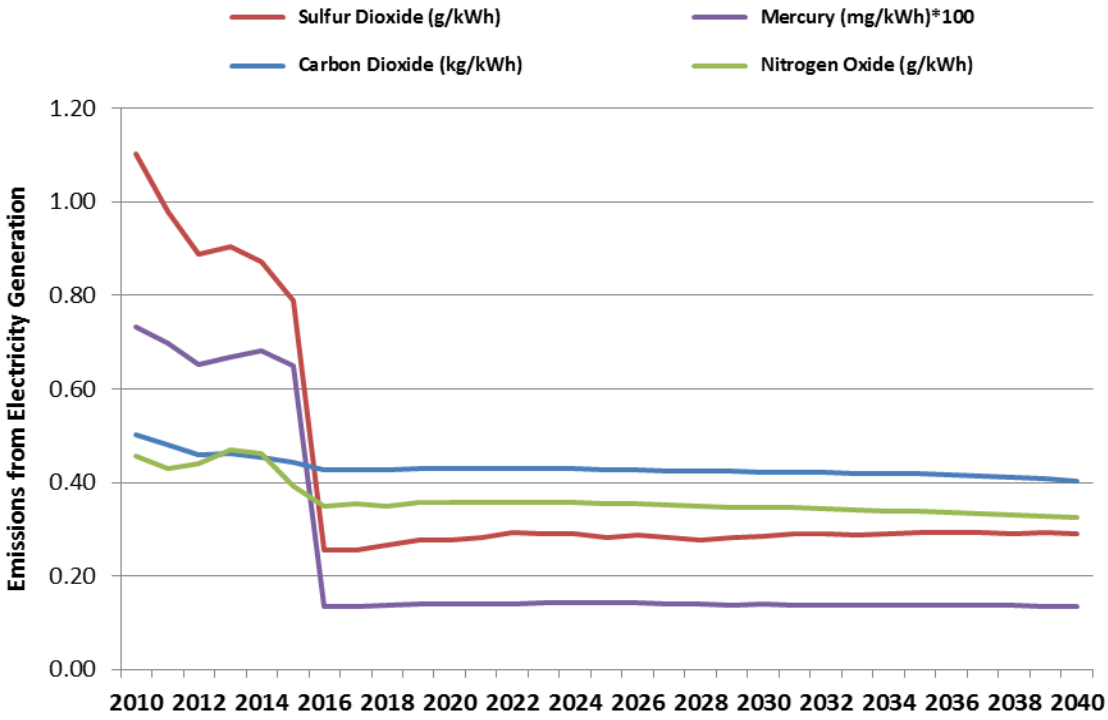


Source: eGRID 2012

Emissions are also affected by the timing of PEV charging, because utilities' electricity generation mix varies by time of day. Marginal CO_2 rates within a region can vary by time of day by more than a factor of two (Zivin et al. 2012).

On the whole, PEV emissions will decline over time. The Mercury and Air Toxics Standards (MATS), adopted by the Environmental Protection Agency (EPA) in 2011, will modestly reduce CO_2 and NO_x emissions and significantly reduce SO_x and mercury emissions from electricity generation beginning 2016, as shown in Figure 4 (EIA 2013b). NO_x and SO_2 emissions account for a large part of the health impacts shown in Table 4. The reduction in emissions will follow from improved control technologies for power plants, as well as the fuel-switching and generation efficiency improvements discussed earlier. Furthermore, proposed regulation of CO_2 emissions from new power plants emissions and potentially regulation of CO_2 from existing power plants in the future may bring additional reductions.

Figure 4: Projected CO_2, SO_2, NO_x, and Mercury Emissions from Electricity Generation



Source: EIA 2013b

Emissions from gasoline-powered vehicles will also decline, however. Vehicle GHG emissions will fall sharply through 2025 as a result of recently adopted standards, largely through fuel economy improvements. In addition, the EPA's recently proposed Tier 3 Motor Vehicle Emission and Fuel Standards would lower the sulfur content in gasoline and tighten tailpipe emissions standards (EPA 2013b). The result would be major reductions in the in-use NO_x, SO_x, and particulate emissions of gasoline-powered vehicles.

Thus, unlike the clear-cut benefit PEVs provide in oil savings, the GHG and criteria pollutant impacts of PEVs relative to gasoline-powered vehicles are complex, varied, and in flux. An all-electric vehicle typically has far lower GHG emissions than a conventional gasoline-powered vehicle, especially in areas with a clean electric grid. In particular, in California, where nearly 40% of U.S. PEV sales have occurred to date (Brown 2013), the grid is much cleaner than average. At the same time, as the efficiency of gasoline-powered vehicles improves over the next 10 to 15 years, the most efficient gasoline vehicles will close this gap unless the de-carbonization of the electricity grid proceeds more rapidly than promised by policies in place today. In the case of criteria pollutants, a gasoline-powered vehicle on the whole performs somewhat better than a PEV charged on a national average electricity mix. Proposed reductions in gasoline sulfur content and power plant emissions would result in lower criteria emissions from both vehicle types; the relative magnitude of emissions in the future remains to be seen.

Taking a longer view, an alternative to gasoline-powered vehicles will be needed to meet climate goals. A recent National Research Council panel found that reducing light-duty vehicles' GHG emissions 80% by 2050 cannot be achieved using only petroleum fuels or natural gas, but will require the use of biofuel, electricity, or hydrogen as fuels (NRC 2013). Which of these fuels or what combination of the three will be most suitable remains to be seen given the complex fuel, vehicle, infrastructure, and consumer issues to be resolved, so continued investment in all of them is necessary. All three fuels would need to have full-fuel-cycle carbon emissions far lower than is typical today to be useful in meeting climate goals.

PEVS AND THE ELECTRIC GRID

As PEVs become more widely used, their effects on the electrical grid will grow, bringing challenges as well as potential benefits. Adding PEVs to the U.S. vehicle fleet will increase electricity demand; and the ability of the grid to respond to that additional demand, and the costs of doing so, will depend upon both the magnitude and the timing of that additional demand. The consequences—and benefits—will vary across the particular supply and infrastructure characteristics of the local/regional electricity grid.

Impact on Electricity Generation

Current electricity generating capacity can accommodate many millions of PEVs entering the U.S. vehicle fleet—as long as vehicle charging is timed to avoid peak demand periods. If the current U.S. light duty auto fleet were charged overnight, nearly 75 percent of the fleet could be composed of PEVs without creating the need for any new power plants (PNNL 2007). A U.C. Davis study found that having 1 million plug-in hybrid-electric vehicles on the road in California (out of 26 million vehicles) would increase total electricity consumption by only one percent (Yang and McCarthy 2009). A number of other studies concur (e.g., PNNL 2007; ORNL 2008; MIT 2011). Hence PEV sales could expand far beyond current sales levels without creating any difficulty for U.S. electric generating capacity. One important caveat, however, is that the timing of vehicle charging must be managed as PEVs' use increases so that the charging does not cluster into peak demand periods. This issue is more fully discussed in the next two sections.

Impact on Electricity Distribution

The impact of PEVs at the utility distribution system level is potentially much more significant than at the generation and transmission levels. The three critical factors influencing the potential effects are: when vehicle charging occurs, where that charging occurs, and at what "level" the charging is conducted. The Society of Automotive Engineers has established charging standards (Standard J1772) that cover two charging power levels, Level-I of up to 1.92 kilowatts and Level-II of up to 19.2 kilowatts. (See Table 6 below.) While a plug-in hybrid might be charged conveniently using a Level-I charger, an all-electric vehicle would require an extended charging period at a Level-I charger and thus would more typically use a Level-II charger. Given that a typical home's peak demand is no more than 4 to 6 kilowatts, PEVs, especially all-electric vehicles, will add substantially to demand on the local distribution system. The Edison Electric Institute (EEI 2011) warned utilities that:

Some localized disruptions may occur, however, in neighborhoods with high PEV adoption, or where distribution transformers are already overloaded due to load growth or older distribution loading standards, and assets have little marginal load capacity. A number of PEVs recharging at the same time may, in some cases, shorten transformer life too, due to their larger power draws.

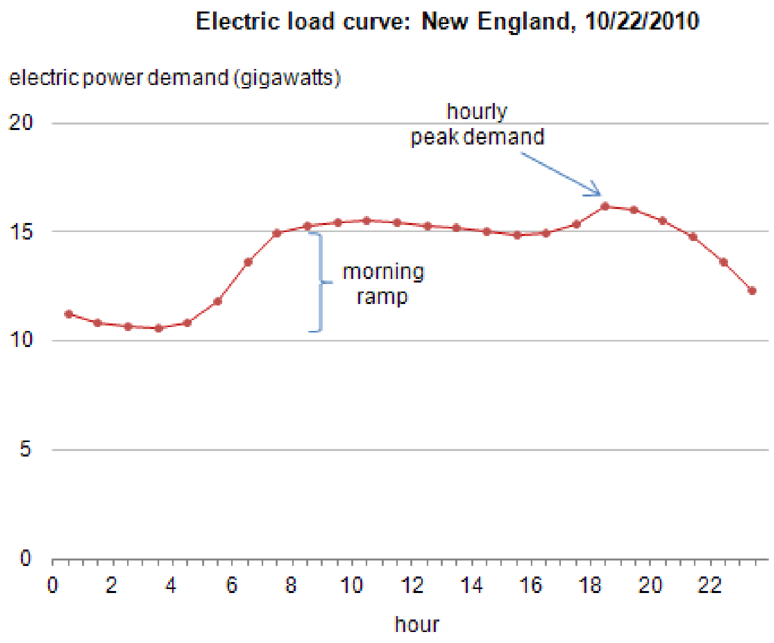
This issue could manifest itself even in a period where overall sales of PEVs are not large, as PEV ownership can cluster in particular neighborhoods (MIT 2011). Early adopters are likely to have higher incomes, and word-of-mouth marketing often occurs in neighborhood settings. Because charging an all-electric vehicle with a Level-II charger is a larger load than the average house, even a few all-electric vehicles on a distribution feeder could overload that feeder and the associated transformers (MIT 2011).

Timing of Charging the Vehicles

In real estate, the old maxim is “location, location, location.” For PEVs, it’s “timing, timing, timing” (plus a little “location”). PEVs have the potential either to be difficult for the grid to accommodate or to provide a valuable service, depending on whether vehicle charging can be sufficiently controlled. For example, if several PEV owners in the same neighborhood were to plug in their vehicles upon arriving home from work, when residential load peaks occur, this could overtax existing infrastructure.

If the timing of PEV charging can be controlled, for example moved to night-time hours when demand is low, then the effects of PEVs on the electricity system can actually be beneficial. PEVs charging at night would help “fill valleys” in the load curve, more completely using existing generation capacity. Such improvements to the utilization factor of the generation fleet reduce the average cost of electricity generation.

Figure 5: Sample Load Curve



Source: EIA 2011

On the other hand, if PEVs are charged during peak demand periods, capacity requirements for the grid will increase, overall electricity costs will increase, and the entire electricity system from generation through distribution could be placed under stress.

With optimal timing of vehicle charging, the existing generating capacity of the U.S. electric system could support a penetration level of plug-in hybrid-electric vehicles of 34% without increasing peak demand on the electric system (Dowds et al. 2009). In contrast, if a high proportion of the charging occurred during peak periods, a 25% penetration of plug-in hybrid-electric vehicles could require an additional 30% of electric generation capacity (ORNL 2008).

At the local distribution level, timing of charging is even more important because many individual components of the distribution system can be at or near peak capacity levels even if there is ample overall generation capacity. DTE Energy (formerly Detroit Edison) recently conducted a study looking at the impact of plug-in hybrid-electric vehicles on components of the distribution system. They examined the effects of just three plug-in hybrid- electric vehicles being added to the load served by a typical transformer, charging from 5:00 to 7:00 PM on a warm summer day, and found that design capacity was exceeded on both 25kVA and 50 kVA transformers. They concluded this could lead to voltage dips, service interruption, and transformer failure (MIT 2011). Another DTE Energy study found that with controlled charging starting at midnight, a 20% PEV penetration rate could be accommodated with no transformer overloads, whereas with uncontrolled charging, the likely charging patterns (e.g., heavy charging when residents return from work each day) could lead to over one-fifth of the transformers experiencing overload conditions (DTE Energy 2011).

Options for Controlling Timing of Vehicle Charging

There are two basic strategies for managing the timing of PEV charging. Utilities may:

- Use time-differentiated electricity tariffs to influence customer decisions on when to charge or
- Directly control charging times through a centralized control structure

A variety of different designs are possible for time-differentiated pricing structures. These range from a fixed time-of-day structure on every day (or every weekday) to a completely flexible real-time price. The latter variable pricing approach requires some type of "smart" technology whereby the charging station responds automatically (based on programmed instructions) rather than relying on the customer to constantly monitor price conditions and respond manually.

Direct control mechanisms also would involve differential rate structures or other financial incentives to persuade customers to yield charging control to the utility. The difference from the first strategy is that the utility retains ultimate physical control over the charging time rather than relying on customers to respond to a price signal in real time.

One challenge confronting any mechanism seeking to manage the timing of vehicle charging is the strong element of American culture that associates driving a car with freedom.[2] Car owners are often reluctant to give up the ability to drive their car whenever they wish. This tendency raises some uncertainty regarding the ability of voluntary pricing structures to manage charging times reliably. Even mechanisms featuring central control of charging times will likely need to allow some opportunity for the car owner to override the utility's control—in exchange for an additional cost.

Because experience with these vehicles to date is limited, the effectiveness of various pricing and control strategies is not yet well understood.[3] One might anticipate, for example, that homes with a gasoline-powered vehicle available as well as an all-electric vehicle might more reliably comply with charging restrictions, or that plug-in hybrids, with their fuel-powered engine capabilities, might provide customers with the ability to be more flexible; but such ideas at this point are conjecture.

PEVs as a Source of Grid Electricity

Clearly, PEVs constitute a load to be served by the utility system. However, PEVs' batteries may also be able to serve as a distributed source of electricity for the grid—distributed storage (Kempton and Tomic 2005; Peterson et. al. 2010; Carson 2010). The concept of electric vehicles as a utility system supply resource is "vehicle to grid" operations, or V2G. With the proper infrastructure to enable and coordinate bi-directional power flow, V2G uses for PEVs could theoretically serve a number of

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[2] One need only watch commercials advertising cars, sport utility vehicles (SUVs), and light trucks to see a heavy dose of that emotional element.

[3] A recent national review found only 22 utilities nationwide offering PEV-specific tariffs (Smart Grid News 2012).

important supply-related functions for the electric grid. Three existing power markets where PEVs hold potential as a supply resource include the following (Kempton and Tomic 2005):[4]

- *Peak power*: electricity provided during the times of highest electric system demand, typically hot summer weekday afternoons and early evenings.
- *Spinning reserve:* electricity generators ready to respond quickly in case of generation failures somewhere in the system or unanticipated spikes in demand.[5] These generators are called upon infrequently (perhaps 20 times a year) and for limited time periods (ten minutes to an hour or more), but are critical for maintaining system reliability.
- *System regulation:* sources of electricity generation that are nimble enough to provide near instantaneous power input in order to keep the system frequency and voltage steady. These types of resources are called upon as many as 400 times a day.

Spinning reserves and system regulation are typically paid for at least in part on a capacity basis, compensated for being on call. These categories of resources account for 5–10% of total electric system costs (Hirst et al. 1997), or at least $10 billion annually in today's market. While PEVs are unlikely to be practical or cost-effective for base-load power, they may be suitable for peak power in some cases, competitive for spinning reserves, and highly competitive for frequency regulation (Kempton and Tomic 2005).

There are significant technical, economic, and operational challenges to the use of PEVs as a V2G resource, however (MIT 2011):

- Enabling bi-directional V2G operations would require substantial and expensive modifications to conventional, unidirectional vehicle chargers and controls.
- PEV operation in a V2G capacity would shorten battery life and could create battery warranty issues.
- Utilities would need to add substantial new capabilities for communication and data handling and would incur substantial costs.
- The amount of energy actually available from a PEV would be relatively small and would be constrained by the charging decisions of PEV owners, who will often want to keep the vehicle's charge available for vehicle operation rather than the needs of the grid.
- The actual economic incentives to PEV owners may be relatively small, since the current price paid for things like voltage regulation services are low, and the participation of PEVs in these markets would likely depress prices further.

The practicality of PEVs as a system resource is most evident in the case of a unidirectional system in which the timing of PEV charging is controlled so as to (1) help regulate voltage and (2) ease the

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[4] This source also notes a fourth potential grid use for PEVs at some point: serving as an electricity storage mechanism and back-up power source for intermittent renewable generation sources such as wind and solar.

[5] The term "spinning" often means more specifically that a power plant is operating in an idling mode and can be called upon to input power quickly to the grid, as opposed to requiring a plant to go through a cold start-up, which would take too long to be able to meet the immediate demand.

pressure on operating reserves by interrupting PEV charging when electricity demand overall is peaking. Such a function would be well suited to commercial PEV fleets, with their predictable operation and charging schedules (MIT 2011).

Challenges for PEV Adoption

Potential benefits of PEVs both to users and to society are large. Challenges to widespread adoption of PEVs must be addressed before those benefits can be realized, however.

BATTERY PERFORMANCE AND COST

PEVs' viability depends heavily on the features of their batteries, including cost, durability, storage capacity, and safety. Batteries for PEVs need to operate for an extended duration while maintaining constant energy output, so high energy capacity is essential. These batteries are regularly discharged deeply, so battery life under these demands is also a key consideration. Battery cost and performance have improved greatly in recent years, but further progress will be required to allow high market penetration of PEVs.

While hybrid-electric vehicles have been in the market for over a decade, the demands on their batteries are different: they must provide short bursts of boost power while maintaining a near-constant state of charge (Kliesch and Langer 2006). Almost all hybrid-electric vehicle models used nickel metal hydride (NiMH) batteries until recently, when lithium-ion (Li-ion) batteries were introduced in some models. Li-ion batteries are about one-quarter the size of the NiMH batteries while weighing approximately half as much (Kliesch and Langer 2006). These characteristics make Li-ion batteries more suitable for PEVs. Table 5 compares specific power and specific energy, or the amount of power and the amount of energy per unit mass, respectively, of these energy storage technologies.

Table 5: Characteristics of Energy Storage Technologies

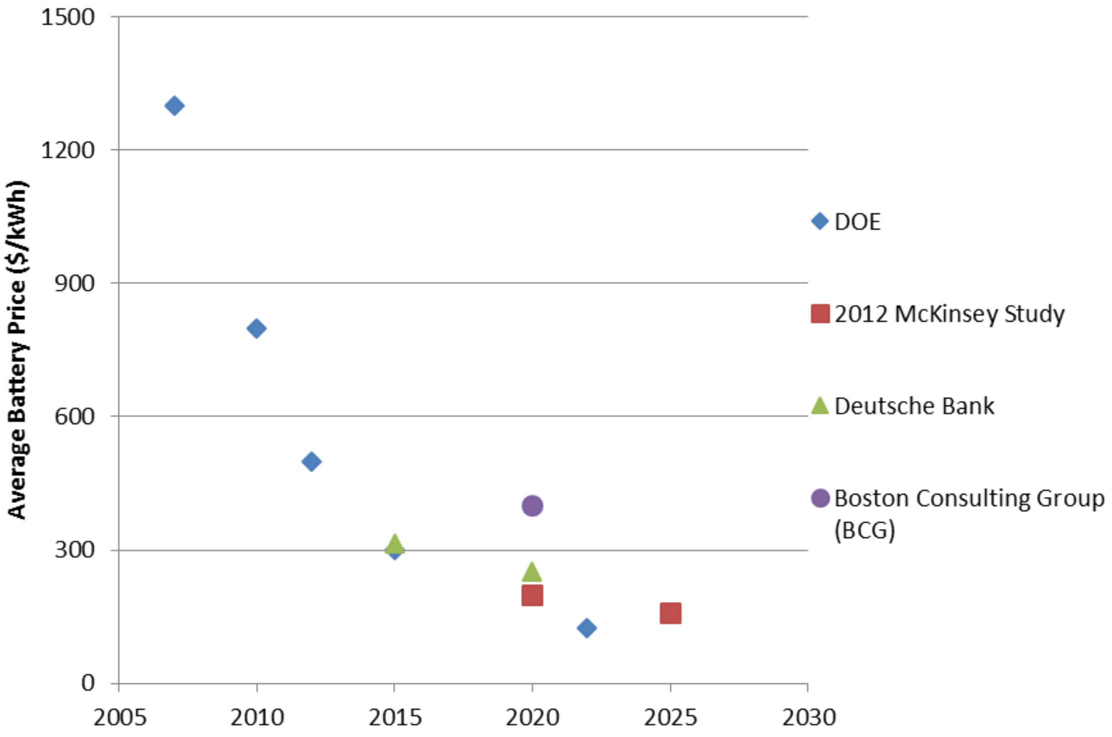
	Specific Energy (watt-hours per kilogram)	Specific Power (watts per kilogram)
Nickel-Metal Hydride (NiMH) Battery	30-80	250-1,000
Lithium-Ion (Li-ion) Battery	150-250	300-1,500

Source: Mi et al. 2011

Presently manufacturers are using Li-ion batteries for all-electrics, plug-in hybrids, and non-plug-in hybrids. The growing PEV market is unlikely to stress the supply of lithium and other raw materials. Researchers have concluded that even rapid PEV adoption could be supported with known lithium supplies for decades, though increased production will be required (Gaines and Nelson 2009; Wadia et al. 2011). Availability of cobalt for use in Li-ion ($LiCoO_2$) batteries could be an issue, especially for the long term.

Battery costs have come down from $1300 per kilowatt-hour (kWh) in 2007 to $500 per kWh in 2012 (Davis 2012).[6] For its program of sponsored research, the Department of Energy (DOE) has set battery cost targets of $300 per kWh in 2015 and $125 per kWh by 2022 (Davis 2012). These targets are consistent with projections of some analysts (McKinsey 2012; Deutsche Bank 2010), while others predict that prices will decline more slowly (BCG 2010). Figure 6 shows the recent progress in reducing battery costs and cost projections to 2025.

Figure 6: Battery Cost Reduction and Cost Projections to 2025



Battery costs can be brought down not only through advances in battery technology but also with higher production volumes, as manufacturers improve the battery manufacturing process (CARB 2011). A 2009 ANL study showed that an increase in production volume from 10,000 batteries per year to 100,000 batteries per year would result in a 37-44% reduction in battery costs (Nelson et al. 2009). A further increase in production volume, from 100,000 to 500,000 batteries per year, would achieve an additional 25-30% cost reduction (Santini et al. 2010).

Although Li-ion technology has provided the necessary launching pad for PEVs, it suffers from an inherent limitation in specific energy. The specific energy of the battery chemistry determines the weight of the battery required to achieve a given electric range. Present research may produce Li-ion batteries with 200 Watt-hr/kg of specific energy; but in order to achieve a driving range comparable to

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[6] Cost figures are at the pack level.

that of a gasoline vehicle, all-electric vehicles will require a battery with a specific energy of 500 Watt-hr/kg. This specification is unlikely to be achieved through Li-ion technology (German 2010). Researchers are working on other potential battery technologies, including lithium air or magnesium-air technology, which could offer cheap, safe, and high-performance batteries (Ashley 2012).

VEHICLE COST

Due largely to the high cost of batteries, the purchase price of a PEV is typically substantially higher than that of a comparable gasoline-powered vehicle. While this price increment presents a challenge for PEV sales, purchase price is not the sole basis on which buyers compare vehicle costs. PEVs' fuel costs are low because they use little or no petroleum fuel.

Table 6 compares purchase cost plus five years of fuel costs for the five cars compared previously with respect to other properties, as well as the Nissan LEAF, a mid-size all-electric vehicle. We have added the LEAF here because it is the highest-selling all-electric vehicle and has a lower sales price than the two other PEVs shown. The last column adjusts purchase plus fuel costs to reflect the current federal tax credit for PEVs. The sales prices shown are for base models. Fuel economy data were taken from www.fueleconomy.gov. We used a fuel price of $3.60 per gallon of gasoline, 12.0¢ per kWh of electricity and $2.10 per gasoline gallon equivalent for natural gas (AFDC 2013c), and did not discount future fuel expenditures. All vehicles were assumed to be driven 12,000 miles per year.

Total cost of ownership involves additional elements, such as maintenance and repair, insurance, and resale value. Because they have no engines and relatively few moving parts overall, all-electric vehicles are expected to have low maintenance costs (AFDC 2012). Resale value will be strongly influenced by expected battery longevity and manufacturer battery warrantee, which is typically 8 years or 100,000 miles for PEVs. Due to the limited data available for these vehicles thus far, we have included only purchase and fuel costs in the comparison.

Table 6 shows that purchase plus fueling costs are lowest for the Prius C hybrid and the gasoline-powered Focus. The 5-year costs of the Focus Electric and the Volt plug-in hybrid are far higher. The LEAF and the Civic Natural Gas fall between the two other groups. When the $7,500 federal tax credit is taken into account, the LEAF costs match those of the gasoline-powered vehicles, while the Focus Electric and the Volt remain $10,000 more expensive.

The 2013 LEAF's starting price of $28,800 is $6,400 below the 2012 price. The Chevrolet Spark will be priced similarly (Automotive News 2013). However, the relationship between vehicles' production costs and their sales costs is not at all transparent, especially in the case of an emerging technology. The relatively low purchase prices of these two vehicles do not demonstrate that the PEV cost problem is solved. At the same time, it is plausible that LEAF sales volumes have been sufficient to drive down manufacturer costs.

Table 6: Purchase and Fuel Costs of Six Model Year 2013 Vehicles

	MSRP ($)	Fuel consumption		5-Year Fuel Costs ($)	MSRP + 5-Year Fuel Costs ($)	With Federal Tax Credit ($)
		Gasoline (gal/mi)	Electricity (kWh/mi)			
Ford Focus FWD	16,200	0.03	N/A	7,180	23,380	23,380
Toyota Prius C	19,080	0.02	N/A	4,308	23,388	23,388
Chevrolet Volt	39,145	0.03	0.35	3,803	42,948	35,448
Ford Focus Electric	39,200	N/A	0.32	2,246	41,446	33,946
Nissan LEAF	28,800	N/A	0.29	2,036	30,836	23,336
Honda Civic Natural Gas	26,305	0.03*	N/A	4,065	30,370	30,370

* Gasoline gallons equivalent

Source: Author's calculations as explained in text

The high upfront cost of today's PEVs is due largely to battery costs. At their current cost, batteries account for about one-third of the total price of an all-electric vehicle. For example, the 2013 Ford Focus electric vehicle is priced at $39,200, out of which the 23 kWh battery pack contributes between $12,000 and $15,000 (WSJ 2012).

If battery costs were to decline to $200 per kWh, the price of a PEV battery would decline by 60%, bringing the price of a PEV down roughly 20% from its 2013 price. On the other hand, the fuel economy of conventional and hybrid vehicles will improve quite dramatically in the coming years, increasing purchase price but reducing fueling costs. Table 7 compares purchase and 5-year fueling costs taking into account anticipated changes in purchase price and fuel efficiency for all vehicle types by 2025. We have kept the fuel price at the 2013 level. It shows purchase and fueling cost for the LEAF without tax credits on par with the gasoline-powered Focus and the Prius C. The Focus Electric and the Chevy Volt would continue to have considerably higher 5-year costs, although the $7,500 federal tax credit would bring these two vehicles' costs within $3,500 of the least costly vehicle. An increase in gasoline price to $5 per gallon in 2025 will make the LEAF, the second least costly vehicle, after the Prius C.

Another approach to reducing the upfront cost of PEVs is to sell the vehicle without the battery. One reason this may prove to be a viable business model is that vehicle batteries have considerable value as energy storage devices in less exacting, non-vehicle applications, and manufacturers, dealers, utilities or other aggregators of these batteries may be able to take advantage of this second use opportunity. PEV leasing can also mitigate the consumer issues of upfront cost, battery replacement and resale value.

Table 7: Purchase and Fuel Costs of Six Vehicles, with Reduced Battery Cost ($200 per kWh) for PEVs and Estimated 2025 Fuel Economy for Gasoline-Powered Vehicles

	MSRP ($)	Fuel consumption		5-Year Fuel Costs ($)*	MSRP + 5-Year Fuel Costs ($)
		Gasoline (gal/mi)	Electricity (kWh/mi)		
Ford Focus FWD	18,806	0.020		4,324	23,130
Toyota Prius C	20,210	0.014		3,010	23,221
Chevrolet Volt	31,316	0.016	0.32	2,760	34,076
Ford Focus Electric	31,360		0.29	2,069	33,429
Nissan LEAF	23,040		0.27	1,875	24,915
Honda Civic Natural Gas	28,776	0.021		2,653	31,429

*Gasoline gallons equivalent

DRIVING RANGE AND CHARGING INFRASTRUCTURE

Most of today's all-electric vehicles have limited driving range. The Nissan LEAF's 24-kWh battery pack provides a 75-mile driving range and the Ford Focus Electric's 23 kWh battery provides a 76-mile range. Both are far less than the 400–mile range of gasoline-powered vehicles. The Tesla Model S all-electric is the exception: it has a range of 208 miles or 265 miles, depending on whether it is purchased with the 60-kWh or 85-kWh battery (Tesla 2013). These large batteries are expensive, however, and the Tesla S has a starting price of about $70,000 to $80,000.

The market research firm J.D. Power found driving range and availability of charging stations to be the top concerns among consumers considering purchasing all-electrics (J.D. Power 2012). Short ranges make it difficult for all-electric vehicles to be used for long-distance travel, and many households may consider an electric vehicle only as a second vehicle. Plug-in hybrids, such as the Chevy Volt, address all-electric vehicles' range limitation by running on gasoline as well as electricity. Having two powertrains is also expensive, however.

The limited range of all-electric vehicles could also be addressed by installing a sufficient number of charging stations so that owners can have their vehicles charged conveniently. While the majority of current charging needs are being met with at-home charging (Nissan NA 2013), charging outside the home would need to be readily available and quick to meet the needs of long-distance travel. Most homes are equipped for either Level-I (low voltage) or Level-II charging, while Level-II or Level-III (high voltage) charging is available at public charging stations. Characteristics of the charging levels are shown in Table 8.

Table 8: PEV Charging Levels

Type of Charging	Location	Electric Outlet	Output Power (kW)	Charging Duration*	Electric Miles from one Hour Of Charging	Installation Costs (US$)	Modification to Electric System
Level-I	Home	120-Volt AC	~1.92	4-10 hours for plug-in hybrid; more than 10 hours for all-electric	2-5 miles	~100	Dedicated circuit for PEVs recommended
Level-II	Home or Public Place	208-240 Volt AC	19.2	3-8 hours for all-electric	10-20 miles	1,000-7,000 (AFDC 2013a, J.D. Power 2012)	Requires dedicated circuit of 20 to 80 amps
Level-III ("DC Fast Charging")	Public Place	480- Volt AC Input	40-50	20-30 minutes for all-electric	180-240 miles	20,000-50,000 (AFDC 2013a)[7]	Requires dedicated 3-phase AC circuit

* Duration varies widely because of the various battery capacities of PEVs
Source: ACEEE with Data from DOE's Alternative Fuels Data Center

Governmental entities have taken steps to increase the number of charging stations. There are more than 5,600 public charging stations in the United States, with more than 13,000 charge points (AFDC 2013a). However, more than 98% of charging stations are either Level-I or Level-II, while only 2% (132 stations) offer Level-III or DC fast charging (AFDC 2013a).

Given the small number of Level-III charging stations, duration of charging remains an issue, especially for charging points outside the home. Time required for Level-II charging is reduced for vehicles having a 6.6 kW on-board charger, which is not universal today (Chae et al. 2011). Such vehicles can place greater stress on the distribution system, however.

ELECTRIC UTILITY ISSUES

Overall, electric utilities are very supportive of the prospect of bringing large numbers of PEVs onto the grid. An Edison Electric Institute report asserted that:

"Electric transportation has tremendous potential to directly benefit society as a whole—reducing the nation's dependency on foreign oil, increasing national energy security, lowering overall transportation fuel costs, improving air quality nation-wide, and spurring economic development. Utilities have an important role in supporting, encouraging, and enabling this technology. Moreover, the strategic value of integrating electric transportation into your overall corporate goals and

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[7] Nissan is selling these chargers at $15,500 excluding tax and other fees (NissanQC 2013).

objectives is substantial—from new business opportunities, to operational and system benefits, to improved customer satisfaction. Utilities should engage now to shape the future of this market and prepare for being the transportation fuel providers of the coming decades." (EEI 2011, p. 1)

Indeed, electric utilities perceive that they have much to gain from a robust PEV market penetration. If the timing of PEV charging is managed well, PEVs represent a chance to "fill valleys" in the load curve, increase the load factor of existing power plants (and in some cases their operating efficiency), and increase revenues at relatively low marginal costs. Electric utilities also see the introduction of PEVs as very compatible with their interest in advancing the use of smart grid technologies, which are seen as important in facilitating the optimal timing of PEV charging.

However, there are some down-side risks to utilities if the timing of PEV charging is not properly managed, including stress on distribution system components, possible stress on peak generation capabilities, and increased costs.

Utility Regulators

While utility regulators see potential benefits to the electricity system from increased PEV penetration in the form of higher load factors for generating plants and higher revenues for utilities, they recognize the risks to the system if the timing of PEV charging cannot be adequately controlled. If PEVs increase system loads at the wrong times (during peak hours), system reliability could be weakened, and costs could increase for all customers.

Even under a design that does a good job of managing the timing of PEV charging, there will be additional costs imposed on the distribution system for handling the increased load. As Dowds et al. (2009) pointed out:

> Even off-peak charging, however, may have an impact on the service life and maintenance costs of the distribution circuits. Transmission lines, generators phase correcting capacitors and transformers will all experience increased loading if [electric vehicles] come into widespread use. (p. 5)

Regulators will have to decide how to allocate these costs between customers charging the PEVs and the remaining ratepayers. "Cross-subsidies" for PEV adoption that utilities may want to pursue to advance the use of PEVs can raise concerns of fairness. Such policies, which include subsidized rates for PEV charging, subsidization of the equipment and installation costs for charging equipment, and charging all ratepayers for distribution system upgrades needed due to PEV load, are discussed further below.

Utility Ratepayers

Ratepayers' perspectives on the consequences of an influx of PEVs onto the electric grid vary according to (at minimum) whether they themselves operate a PEV. From the perspective of a non-PEV-owning ratepayer, the prospect of a substantial influx of PEVs presents some significant concerns. These concerns may include:

1) *The possibility of all ratepayers subsidizing the service of PEV charging.* If the tariffs used in billing for PEV charging do not allow the utility to fully recover the costs of providing that service, and if other funding is not available to cover those costs, then other ratepayers may subsidize the costs).
2) *The possibility of all ratepayers subsidizing the equipment and installation costs for the charging equipment.* Unless PEV drivers themselves are paying the full costs of all the charging equipment and installation, or external funding is available to offset these costs, other ratepayers will subsidize this equipment.
3) *The risk of service interruption.* If PEV charging creates stress on the distribution system, service interruption may result.
4) *Additional costs for distribution system upgrades needed to accommodate PEV charging.* The additional cost to the utility system for these upgrades could be a substantial expense.

At the same time, ratepayers as a whole may benefit from greater PEV use. PEVs' potential to increase system asset utilization by increasing the load factor could lead to reduced rates for all customers.

Existing PEV Policies and Programs

All levels of government have launched policies and programs addressing the challenges of bringing PEVs into the market. This section discusses federal policies and programs in some detail and gives an overview of measures adopted by state and local governments. It concludes with a summary of utility regulatory policy related to PEVs.

FEDERAL POLICIES AND PROGRAMS

Consumer Tax Credit

Since January 2010, a federal tax credit of $2500 to $7500, depending on battery capacity, has been available for the purchase of a PEV with gross vehicle weight rating of less than 14,000 pounds. Eligible vehicles must draw power from a battery of at least four kWh that can be recharged from an external source of electricity. The credit begins to phase out for a specific manufacturer's vehicles when that manufacturer has sold at least 200,000 qualifying vehicles, cumulatively, for use in the United States (IRS 2013). As of the end of the first quarter of 2013, IRS shows cumulative PEV sales of 26,010 vehicles, of which 9,207 were Ford PEVs and 16,803 Nissan.

Tax credits can help PEVs become competitive with hybrid-electric vehicles and gasoline-powered vehicles by reducing their high purchase price. For example, a tax credit of $7,500 brings the five-year ownership cost of the 2013 Nissan Leaf less below that of a comparable conventional vehicle.

Light-Duty Vehicle Fuel Economy and Greenhouse Gas Rules

Federal programs of standards for fuel economy and greenhouse gas emissions for light-duty vehicles encourage manufacturers to produce PEVs. PEVs perform well under both standards; and since manufacturer compliance with the standards is based upon the average performance of vehicles produced, PEVs can help manufacturers meet the standards. To better understand these incentives, it is necessary to look at the details of the programs.

Corporate Average Fuel Economy (CAFE) standards, administered by the National Highway Traffic Safety Administration, use a fuel economy calculation method for PEVs that yields high values for these vehicles. The CAFE program was adopted in the Energy Policy and Conservation Act of 1975 to reduce energy consumption, and oil consumption in particular, in the wake of the oil crisis in 1973. The program measures vehicle efficiency in miles per gallon for gasoline vehicles and defines equivalent metrics for other vehicle running on other fuels. In the case of a PEV, miles per watt-hour is converted to miles per gasoline gallon equivalent using a Department of Energy-defined Petroleum Equivalency Factor of 82,049 watt-hours per gallon (DOE 2011). The Petroleum Equivalency Factor reflects i) the energy embodied in gasoline and electricity on a full-fuel cycle basis, and ii) a factor of 0.15 applied to electricity energy content adopted in the CAFE program to reward the use of non-petroleum fuels. The use of full fuel cycle energy content for electricity reduces mile-per-gallon equivalent fuel economy of an electric vehicle, while the factor of 0.15 increases it; the net effect of using the Petroleum Equivalency Factor is high fuel economy values for all-electric vehicles. The Ford Focus Electric, which travels 4.44 miles per kilowatt-hour on a combined city-highway cycle under laboratory conditions, would achieve a fuel economy of 364 miles per gallon equivalent under the CAFE program. Hence production of substantial number of these vehicles would greatly aid the manufacturer's average fuel economy.

It should be noted that the regulatory CAFE value is far higher than the energy performance from the user's perspective, as can be seen by comparing the CAFE fuel economy to the value on the fuel economy label found on new cars. The label fuel economy of the Focus Electric is 105 miles per gallon, several times lower than the CAFE fuel economy. The label value reflects an electricity-to-petroleum conversion factor of 33,705 watt-hours per gallon, based on only the energy consumed in driving the vehicle, not the full fuel cycle energy. Furthermore, the label fuel economy for these vehicles, as for all other vehicles, reflects a downward adjustment of the test fuel economy to reflect "real-world" driving conditions rather than laboratory driving conditions. As a result, the CAFE fuel economy of any all-electric vehicle is about 3.5 times higher than its label fuel economy.

Federal standards for vehicles' emissions of GHG, first implemented in 2012, also incentivize PEV manufacture. The rule counts early-production all-electric vehicles, as well fuel cell vehicles, as zero-emissions vehicles and thus does not take into account the emissions associated with fuel production. It treats plug-in hybrids as zero-emissions vehicles while they operate on off-board electricity.

The zero-emissions treatment of these vehicles is limited to either the first 200,000 or the first 300,000 PEVs and fuel cell vehicles produced by a given manufacturer during model years 2012–2016, according to whether the manufacturer produces fewer or more than 25,000 PEVs and fuel cell vehicles in the 2012 model year. There are higher caps on PEVs and fuel cell vehicles for the manufacturers already producing these vehicles at the beginning of the rulemaking period, rewarding the early entrants in these markets. The manufacturers taking advantage of this incentive will have increased PEV sales, and, therefore, prices of their PEVs are likely to decline due to economies of scale. Reduction in price for the PEVs of these early adopters will also put pressure on other manufacturers, resulting in reduced prices for PEVs from all manufacturers.

For 2017–2021, the GHG emissions rule does not place any limit on the number of PEVs considered to be zero-emissions vehicles. For model years 2022 through 2025, up to 600,000 vehicles will be treated as zero-emissions vehicles for companies that have sold 300,000 PEVs and fuel cell vehicles in model years 2019–2021 and up to 200,000 vehicles for all other manufacturers.

In addition, each PEV and fuel cell vehicle of model years 2017 through 2021 will count as more than one vehicle in the manufacturer's compliance calculation. Electric vehicles and fuel cell vehicles will start with a multiplier value of 2.0 in model year 2017, phasing down to a value of 1.5 in model year 2021. Plug-in hybrid-electric vehicles will start with a multiplier value of 1.6 in model year 2017 and phase down to a value of 1.3 in model year 2021. No multiplier would be provided for model years 2022–2025.

The multiplier together with the zero-emissions treatment provides a strong incentive for PEV production. Production of one all-electric vehicle would be more than sufficient to provide the emissions reductions required for nine average model year 2016 vehicles to meet the 2019 standard, facilitating a manufacturer's compliance.

These PEV-related provisions of fuel economy and GHG standards increase the value of PEV production, making it "an integral part of the manufacturers' CAFE and GHG compliance strategies," according to executives of major auto manufacturers (Automotive News 2012). Furthermore, any manufacturer approaching the production caps for zero-emissions treatment of PEVs would be likely to realize major reductions in cost. As noted earlier, annual production of 100,000 PEVs could bring down battery prices by 37-40%, which would lower the overall price of PEVs on the order of 15% in subsequent years.

However, even as these provisions encourage the production of PEVs, they overstate PEVs' actual contributions to reducing emissions. As a result, the provisions will reduce the standards' GHG reductions by permitting manufacturers to sell more high-emitting vehicles than they otherwise would be able to sell under the standard. EPA projected a decrease of 25 million metric tons of GHG emissions reductions that would be associated with adding 500,000 electric vehicles during model years 2012 to 2016 (EPA and NHTSA 2012). The standard's treatment of PEVs also fails to encourage manufacturers' efforts to increase PEVs' efficiency or to promote their charging on low-carbon electricity, for example by focusing sales in areas that have a low-carbon generation mix or on buyers with solar installations.

Investment in Research, Development, and Deployment (RD&D)

Several PEV initiatives were introduced in the American Recovery and Reinvestment Act of 2009 (ARRA). ARRA provided $2.0 billion in grants, administered by DOE, to establish advanced battery and power electronics and motor manufacturing to manufacturers and suppliers located in the U.S. These grants were aimed at providing support to manufacturers in bringing the prices of their products, especially batteries, within consumers' reach. The majority of these grants ($1.5 billion) were made to manufacturers to produce batteries for PEVs, and the remaining $500 million went to manufacturers of electric drive components such as electric motors. ARRA also allocated $400 million for transportation electrification demonstrations, infrastructure, and education (Canis 2011).

The Advanced Technology Vehicle Manufacturing Incentives, authorized in the Energy Independence and Security Act of 2007 (EISA), has provided over $34 billion in loans to the U.S. automotive industry to support the manufacture of high efficiency vehicles and their components. Manufacturers may be eligible for direct loans for up to 30% of the cost of re-equipping, expanding, or establishing manufacturing facilities in the U.S. used to produce qualified advanced technology vehicles, including PEVs. Ford Motor Company and Nissan North America Inc. received $5.9 billion and $1.5 billion, respectively, for all-electric vehicle manufacturing facilities (DOE 2013b).

Spurred by President Obama's goal of putting one million electric drive vehicles on the road by 2015, DOE provides extensive support for PEVs through its annual budget. Approximately half of the budgets of DOE's Vehicle Technologies program in fiscal years 2012 and 2013 have gone to research, development and deployment for PEVs (Davis 2012). Programs supporting PEVs include the Energy Innovation Hub program, the Advanced Energy Research Projects Agency—Energy (ARPA-E), Improved Energy Technology Loans, the Clean Cities Program, and the State Energy Program (SEP). Activities under these programs are described in Table 9.

Several bills specifically to promote production and deployment of PEVs were introduced in the 111th and 112th U.S. Congresses (2009-2012). While none of these bills became law, they contained provisions that would have complemented existing programs and policies to accelerate adoption of PEVs. Two notable bills were H.R. 5442 / S. 3442, the Electric Drive Vehicle Deployment Act of 2010, and S. 948, Promoting Electric Vehicles Act of 2011. In addition to providing major funding for research and development, these bills addressed such issues as installation of charging infrastructure, PEV deployment communities, a prize for a 500-mile battery, technical assistance to states and local governments and communities, smart grid integration, updating building codes, and education and training.

Table 9: DOE Investment in PEV Research, Development, and Deployment

Program Type	Description
Energy Innovation Hub	A new Batteries and Energy Storage Hub, awarded $120 million over 5 years, will be led by Argonne National Laboratory. It will combine the R&D of five DOE national laboratories, five universities, and four private firms in an effort to achieve revolutionary advances in battery performance
Advanced Research Projects Agency—Energy (ARPA-E) Grants	ARPA-E grants focus on various concepts in multiple program areas, including vehicle technologies and energy storage. In 2012, ARPA-E allocated $130 million in funding through its "OPEN 2012" program for 66 research projects, including battery and smart grid research projects. See http://arpa-e.energy.gov/Portals/0/Documents/Projects/OPEN2012_ProjectDescriptions_FINAL_112812.pdf
Clean Cities Program	Clean Cities promotes deployment of alternative fuels and advanced vehicles, fuel blends, fuel economy, hybrid vehicles, and idle reduction. In 2012, Clean Cities awarded 20 alternative-fuel market projects totaling $11.1 million. These projects will help increase the use of alternative fuel vehicles, including those that run on electricity. See http://www1.eere.energy.gov/cleancities/alternative_fuel_market_projects.html.

STATE POLICIES AND PROGRAMS

Several states have also taken steps to promote PEV technology. California in particular has put in place a wide array of policies over many years, as discussed below. In Maryland, consumers can claim a $2,000 tax credit for a PEV purchased between October 2010 and July 2013. Illinois provides consumers with 80% of the incremental cost, up to $4,000, of purchasing a PEV or other alternative fuel vehicle. Hawaii provides rebates of 20% of electric vehicle and charging equipment purchase price (up to $4,500). States including Georgia, Louisiana, Montana, and West Virginia offers income tax credits for the purchase of alternative fuel vehicles including PEVs. Some states also offer assistance to manufacturers, the utility industry or consumers that includes reduced electricity rates for PEV charging, sales tax exemption for buying charging infrastructure, smart grid infrastructure support, and credits for battery manufacturing. Others provide reduction or elimination of the vehicle license tax, exemption from state inspection and maintenance programs, use of high–occupancy vehicle (HOV) lanes, and eligibility to park in special areas. State incentives are compiled in a Carnegie Endowment report (Gordon et al. 2012) and on the DOE Alternative Fuels Data Center web site (AFDC 2012). While some of these policies are similar to those adopted at the federal level, the range of activities across the states is larger and, in some cases, they are more appropriate as state-level activities.

California Policies and Programs

The state of California has been a pioneer in the promotion of advanced technology vehicles, including PEVs. California's setting of GHG emissions standards for vehicles in 1990 was instrumental in advancing fuel economy and GHG standards at the federal level, and the state is a full partner with the federal agencies in implementing and further advancing harmonized standards.

In 2005, the state of California set a goal to reduce its GHG emissions from all sources to 80% below 1990 levels by 2050. The state's 2009 assessment of vehicle technologies demonstrated that in order to reach the 2050 emissions target, the passenger vehicle fleet would need to be dominated by fuel cell vehicles (approximately 50%) and electric vehicles (approximately 37%). Plug-in hybrid-electric vehicles, hybrid-electric vehicles, and advanced gasoline vehicles would together constitute the remaining 13% in this analysis (CARB 2011).

An important tool in achieving California's 2050 GHG reduction goal is the state's Zero-Emission Vehicles (ZEV) Program, introduced in 1990 to dramatically reduce the environmental impacts of light-duty vehicles through the gradual introduction of zero- or very low-emission vehicles into the California fleet. By 2011, the ZEV program had supported the introduction of about 5,600 all-electric vehicles and fuel cell vehicles, as well as 28,800 neighborhood-electric vehicles (CARB 2011). ZEV sales would rise further with the adoption of the revised ZEV program by the Clean Air Act Section 177 states,[8] including Connecticut, Maine, Maryland, Massachusetts, New Jersey, New Mexico, New York, Oregon, Rhode Island, and Vermont, and the District of Columbia. According to one estimate,

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[8] Section 177 of the Clean Air Act allows states to adopt vehicle emissions standards that are identical to California standards approved by EPA.

by 2015 the program will generate cumulative sales of 115,000 to 370,000 ZEVs in California and 1.0 to 1.3 million nationally (Mui and Baum 2010).

Another California program providing an incentive for PEV adoption is the Low Carbon Fuel Standard (LCFS). The LCFS rule requires that PEV users receive the full value of the credits generated under the program by the use of electricity as a transportation fuel (Brown 2013).

California has adopted several other measures that will help to accelerate PEV adoption, including:

- Manufacturers and other private entities can obtain sales and use tax exclusions on qualified property that is used to develop and commercialize advanced transportation technologies, including electric and fuel cell vehicles.
- Consumers are eligible for rebates of up to $2,500 for the purchase or lease of qualified light-duty zero-emission and plug-in hybrid vehicles through the Clean Vehicle Rebate Project.
- Companies have received grants for installation of publicly accessible charging stations and development of advanced charging systems, such as Coulomb Technology's "smart charger network" that can remotely shift charging loads away from peak periods.
- Qualified PEVs using high-occupancy vehicle (HOV) highway lanes are exempt from the occupancy requirements typically applicable to users.

There are numerous regional, municipal and private sector initiatives as well, including discounted electricity rates for PEV charging offered by Southern California Edison, Pacific Gas & Electric, and various municipal districts.

In addition to the extensive programs and policies already in place, California has systematically considered the steps that would be required to create a comprehensive plan to scale up PEVs and other ZEVs. The Governor issued an Executive Order in 2012 to promote ZEV adoption, setting a milestone of 1.5 million ZEVs on California's roadways by 2025, among other targets (Brown 2012). The Executive Order also directs state governments to purchase 25% ZEVs for its light-duty fleet in 2020. An interagency working group prepared the 2013 ZEV Action Plan (Brown 2013), which sets out in detail actions required to meet the plan's four goals: (1) complete needed infrastructure and planning; (2) expand consumer awareness and demand; (3) transform fleets; and (4) grow jobs and investment in the private sector.

While the roles of federal and state governments in promoting PEV adoption will necessarily differ, California's systematic and comprehensive approach to the issue provides useful indications of where gaps may exist at the federal level and how state actions could complement federal actions.

LOCAL POLICIES AND PROGRAMS

Some local governments in the U.S. have put in place PEV policies and programs, including targets for PEV ownership, financial incentives for PEV purchase and for installation of charging stations, electricity rate discounts for PEV charging, and purchase of PEVs for their fleets (RMI 2012, AFDC 2012). Some of these programs are eligible for federal deployment grants under DOE's Clean Cities Program. Table 10 shows policies adopted by four U.S. cities to promote PEVs.

Table 10: PEV Policy Initiatives in Four U.S. Cities

City	Financial Assistance	Other Policies
Los Angeles, CA	80,000 PEV target for 2015 $2,000 charging station rebate for residential customers (LA Department of Water and Power) Discounted rate for the first 500 kWh of electricity used per month to charge PEVs during off-peak times.	City building codes contain EV-readiness requirements for all new construction as of Jan. 1, 2011
New York, NY		Purchase of PEVs for the City All-electric vehicle taxi pilot program with Nissan
Portland, OR	Target of 30,000 PEVs by 2015 Free charging for PEV owners who agree to anonymous data collection Choice of flat rate or time of use electricity rates specific to PEV owners.	
Riverside, CA	$2,500 consumer incentive for PEVs purchased from any Riverside dealer.	

Source: Compiled from 2012 EV City Casebook (RMI 2012) and AFDC 2012

UTILITY REGULATORY POLICIES

A wide range of utility regulatory policies could strongly influence the rate of adoption of PEVs. These include (Greenwald and Nigro 2012; Baumhefner et al. 2012):

- Requiring utilities to assess their system's capacity to accommodate an influx of PEVs and identify potential infrastructure needs
- Allowing cost recovery for upgrades to distribution systems and other infrastructure investments by utilities that are necessary to achieve substantial market penetration of PEVs
- Establishing appropriate PEV charging rates
- Providing support for siting and installing PEV charging equipment

Requiring Utilities to Conduct PEV Infrastructure Planning

One low-risk initial step that utility regulatory commissions can take is to require utilities to engage in a planning process to assess their system capability to accommodate PEV market penetration and identify potential infrastructure needs and associated costs. This was contemplated as a federal requirement in the Waxman-Markey climate change bill HR 2454 of 2009, but the bill was never enacted. In jurisdictions where utilities have not already done so, it would seem that regulatory commissions could require their utilities to engage in such an assessment as a matter of prudent business planning.

Allowing Cost Recovery for Distribution System Upgrades and Other Infrastructure Investments

In order for utilities to undertake the necessary infrastructure improvements—whether upgrading local distribution transformers, adding substations, or adding transmission-level capacity—it will be necessary for utilities to recover their costs for those investments. Appropriate cost-of-service impacts will need to be identified and proper cost allocation ensured.

Establishing Appropriate Rates for Electric Vehicle Charging

Establishing appropriate vehicle charging rates is a key area for regulatory action with regard to PEVs. Rates must be low enough to promote PEV adoption by customers, and the rate structure must adequately manage the timing of vehicle charging.

Several different rate design options have been implemented in various locations, including:

- Time-of-use rate applied to the whole house
- Time-of-use rate applied to separately metered vehicle charging
- Flat monthly charge for separately metered vehicle charging
- Various combinations of the above, including seasonal rate differentials and consumption limits on discounted rates

Actual experience with such rate designs is limited, however. A national review conducted in mid-2012 found that only 22 utilities nationwide (about 6%) had a PEV tariff in place (Smart Grid News 2012).

Providing Support for Siting and Installing PEV Charging Equipment

The determination of what portion of PEV charging equipment costs should be allocated to the customers using that equipment, rather than to ratepayers generally, will be a central issue for utility regulatory commissions to confront. Material and labor costs for installing PEV charging equipment and necessary wiring, metering, etc. can be very expensive. (Typical costs for a residential Level-I and II chargers can be found in Table 8 of this report.) Utilities will seek to help customers overcome those cost hurdles in order to promote PEV adoption. Utilities can pursue a variety of means to provide customers with credits or rebates to help with these costs, including using state or federal grants or tax credits, as well as utility revenues (EEI 2011).

To the extent that utility revenues are used to help defray those costs, regulatory commissions will need to be sensitive to non-PEV-owning ratepayers' cross-subsidization of PEV infrastructure and charging. Possible rationales for using utility revenues for charging infrastructure include: enabling collection of data on load impacts and customer behavior in order to better plan for PEVs' penetration into the market; leveraging smart grid implementation goals; increasing power plant load factor; and helping to achieve environmental goals (EEI 2011). In addition, if the vision of PEVs as a potential supply resource though vehicle-to-grid operation begins to materialize, then a stronger rationale for ratepayer subsidization of these costs would come into play.

Clarifying Charging Stations Ownership Issues

Another topic that will be important for facilitating PEV adoption is the treatment of "public" charging stations (charging stations that are not located in customers' private homes or facilities, but rather, are designed for open public access). California has taken a lead role in this area and has made a number of rulings, including:

- Directing electric utilities to apply a protocol to support the use of third-party-owned sub-meters and discouraging electric utilities from owning sub-meters
- Prohibiting electric utilities from owning charging stations, except for their own vehicle fleets or employees
- Determining that owners of public vehicle charging stations (referred to as "electric vehicle service providers") are not "public utilities" and will not be regulated as such by the state[9]
- Establishing clear principles for education and outreach efforts by investor-owned utilities to inform customers about PEVs, including available metering arrangements and rates, and the environmental and societal benefits of PEVs

Other Initiatives to Support PEV Adoption

Other initiatives in utility regulatory arena could accelerate PEV adoption in the market, including:

- Utility leasing of PEVs to customers
- Fast-tracking of permitting and installation of PEV charging stations
- Utility ownership of vehicle batteries as a vehicle-to-grid (V2G) resource that utilities can draw upon

Policy Recommendations

PEVs have great potential to reduce oil consumption and, where low-carbon electricity is available, emissions from the transportation sector. There are multiple challenges to PEV commercialization and their integration into the grid, however, and a variety of policies are needed to address those challenges. While a great number and variety of PEV policies are in place already, additional policies would help to achieve widespread adoption of PEVs in the immediate future. Moreover, current policies are not in all cases crafted to best achieve the benefits that PEVs can bring.

Table 11 summarizes challenges for PEV adoption, measures in place to address these challenges, and remaining needs to gain wide-scale adoption of these vehicles.

While some of the remaining needs will best be met by state and local governments and the private sector, several call for action on the part of the federal government or utility regulators. ACEEE recommends that the federal government:

Support further performance improvement and cost reduction for batteries

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[9] This removes a large amount of potential regulatory burden in areas such as required regulatory filings and pricing models and rates. However, the state can still exercise limited jurisdiction over areas such as safety and procurement rules.

In order to fully meet purchase price and driving range requirements for PEVs, further progress on batteries is essential. The federal government should provide steady funding for battery research on cost reduction, longevity, and energy density, as well as alternatives to Li-ion chemistry, for several years to come.

Set policies to help Increase PEV sales volumes

Regulatory programs that require continuing improvements in vehicles' fuel economy and GHG emissions promote PEV production. Reaffirming federal light-duty vehicle standards set to 2025, and strengthening them if feasible, will be a steady driver for PEVs. The standards should be performance-based, however, reflecting full-fuel-cycle GHG emissions.

Congress should consider adopting a revenue-neutral feebate program, in which fees and rebates for new cars would be based on a sliding scale reflecting their emissions of greenhouse gases or fuel consumption (Langer 2005). Such a program would complement fuel economy and GHG emissions standards and could help to bring a broader range of PEVs and other highly efficient vehicles into the market.

Consistent purchase of PEVs for the federal fleet would help build demand for vehicles and batteries. Federal agencies purchased about 18,000 cars in fiscal year 2011; fewer than 500 were PEVs (GSA 2013). The federal government should commit to buying PEVs for 25% of their car purchases annually over the next several years. State, county and local governments together own more than ten times as many cars as the federal fleet (Automotive Fleet 2010), so purchase commitments by state and municipal governments could have a large impact on PEV sales.

Help to improve the charging experience

Local governments, utilities, and the private sector should take the lead on ensuring easy availability and access of PEV charging equipment to consumers. However, the federal government should assist by promoting standardization of charging protocols and reinstating tax incentives for charging station installation. Pilot programs for PEV deployment communities and corridors should be expanded as a means of ensuring adequate density, quality, and coordination of charging infrastructure.

Table 11: PEV Challenges, Policies, and Remaining Needs

Challenges	Policies and Programs in Place	Remaining Needs
Battery performance and cost	• Grants and loans for battery R&D investment in batteries • Research at national laboratories	• Further reductions in battery cost and improvements in performance • Further advances in battery chemistry
PEV sales volumes	• Federal and state purchase incentives for consumers • Regulatory programs that reward PEV production	• Availability in all market segments • Consumer confidence in vehicle resale value
Charging Infrastructure and Duration	• Charging station installation at state and local levels • Establishment of PEV-ready communities	• More public charging stations • Networks of Level-III charging stations on highways • Broad access to all public charging stations
Utility Issues • Transformer overload • Infrastructure upgrade costs • Rate structure for PEV charging	• Time-of-day or PEV-specific electricity rates in some locations	• Policies on PEV infrastructure cost recovery and equitable rate structures • Understanding of PEV owner response to rate structures • Development of smart charging technologies
Policy issues • Road financing • Net environmental Impacts	• Debate on VMT fee, expanded tolling, other complements to gas tax • Proposed power plant emissions reductions • Caps on preferential treatment for PEVs in light-duty GHG rule	• Mechanism for PEV contribution to roadway expenditures • PEV charging consistently on clean electricity

Design policies to maximize PEV benefits and properly account for impacts

Federal policies affecting PEVs should be designed to ensure these vehicles' continuing improvement and to properly account for any costs they may impose. This means defining environmental standards to reflect the actual performance of the vehicles, so as to drive improvements both in vehicles and in electricity generation and identifying taxation policies that ensure PEVs pay their (modest) fair share of transportation infrastructure costs. In particular:

- Emissions of PEVs should be defined for purposes of GHG emissions standards to reflect their full-fuel-cycle emissions. This would ensure that PEVs result in net emissions reductions and keep automakers engaged in efforts to reduce emissions associated with the use of their PEVs.
- Policies to raise revenues for transportation infrastructure should reflect actual impacts of PEVs and other advanced vehicles.
- PEV policies that are inconsistent with optimal use of transportation infrastructure, such as free parking, privileged access to HOV or HOT lanes should be avoided, or at a minimum should be of limited duration.

ACEEE recommends that utility regulators:

Advance utilities' PEV readiness

State utility regulatory commissions need to ensure that their utilities are preparing to accommodate increased PEV market penetration, and work with utilities to develop appropriate PEV charging tariffs. Such tariffs must simultaneously accomplish three objectives: (1) be attractive enough to encourage PEV adoption; (2) be effective at managing the timing of vehicle charging; and (3) be "fair" in the sense of not resulting in unjustified cross-subsidies from other ratepayers.

Utility commissions should require assessments of charging infrastructure needs. They should allow cost recovery for utility programs to promote PEV adoption. At the same time, however, they should determine what portion of charging infrastructure and equipment upgrade cost should be borne by PEV owners, rather than by ratepayers as a whole.

Further research is needed to help in the formulation of utility policy. Among the areas in which additional experience and research will be helpful are actual customer response to different rate designs; true "cost of service" associated with the charging of PEVs; and electricity pricing and charging control strategies.

Conclusions

Plug-in vehicles present an important alternative technology in a market long dominated by petroleum-powered vehicles. Whether PEVs become the predominant technology in the light-duty vehicle market or fill only certain needs within a diverse market will depend upon factors such as future oil and natural gas prices, advances in conventional vehicle and fuel cell technologies, and breakthroughs in battery technology, as well as future decisions on energy and climate policy. Policies to promote the adoption of PEVs in the U.S. vehicle fleet are warranted, both to develop fuel diversity in the transportation sector and to benefit from, as well as promote, the emergence of a low-carbon electricity grid. With forward-looking policy design, the U.S. can and should position itself to take full advantage of PEVs' ability to reduce the nation's oil consumption, reduce greenhouse gas and other emissions, and improve the efficiency of the U.S. electricity grid.

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