ENVIRONMENT IOWA
REASEARCH & POLICY CENTER

Plug-In Cars

Powering America Toward a Cleaner Future

Plug-In Cars

Powering America Toward a Cleaner Future

Environment Iowa
Research & Policy Center

Siena Kaplan
Frontier Group

Rob Sargent
Environment America
Research & Policy Center

January 2010

Acknowledgments

The authors wish to thank Austan Librach, Director of Emerging Transportation Technologies, Austin Energy; David Friedman, Clean Vehicles Research Director, Union of Concerned Scientists; Charles Griffith, Clean Cars Campaign Director, Ecology Center; and Michelle Manion, Head of the Climate and Energy Team, Northeast States for Coordinated Air Use Management (NESCAUM), for their review of this report. Thanks to Tony Dutzik of Frontier Group and Carolyn Kramer for their editorial assistance.

The generous financial support of the Energy Foundation and Jay Harris made this report possible.

The views expressed in this report are those of the authors and do not necessarily reflect the views of our funders or those who provided review. The authors bear responsibility for any factual errors.

© 2010 Environment Iowa Research & Policy Center

Environment Iowa Research & Policy Center is a 501(c)(3) organization. We are dedicated to protecting Iowa's air, water and open spaces. We investigate problems, craft solutions, educate the public and decision makers, and help Iowans make their voices heard in local, state and national debates over the quality of our environment and our lives. For more information about Environment Iowa Research & Policy Center or for additional copies of this report, please visit www.environmentiowa.org.

Frontier Group conducts independent research and policy analysis to support a cleaner, healthier and more democratic society. Our mission is to inject accurate information and compelling ideas into public policy debates at the local, state and federal levels. For more information about Frontier Group, please visit www.frontiergroup.org.

Cover photo: Siena Kaplan
Layout: Harriet Eckstein Graphic Design

Table of Contents

Executive Summary 1

Introduction 5

Plug-In Cars: What Are They and Why Are They Important? 7

Plug-In Hybrids 7

Electric Vehicles 8

Why Use Electricity as a Fuel? 9

Plug-Ins and the Environment 11

Global Warming and Plug-Ins 11

Air Quality and Plug-Ins 13

Plug-Ins and Oil 14

Will the Electric Grid Be Able to Handle Plug-In Cars? 15

Supplying the Electricity for America’s Cars 15

Plug-Ins as a Grid Asset 16

Owning a Plug-In Vehicle 19

Driving a Plug-In Car 19

Staying Charged 20

The Cost of Owning a Plug-In Car 22

Safety 23

Moving Toward a Plug-In Future 25

Getting Plug-Ins on the Road 25

Reaping the Full Benefits of Plug-In Cars 27

Notes 30

Executive Summary

America's current fleet of gasoline-powered cars and trucks leaves us dependent on oil, contributes to air pollution problems that threaten our health, and produces large amounts of global warming pollution. "Plug-in" cars are emerging as an effective way to lower global warming emissions, oil use, and smog. A plug-in car is one that can be recharged from the electric grid. Plug-in cars come in two types: plug-in hybrids that are paired with small gasoline engines, and fully electric vehicles that consume no gasoline at all.

As automakers race to become the first to introduce a mass production plug-in vehicle to American consumers, citizens and decision-makers are grappling to understand the implications of switching to a vehicle fleet fueled primarily by electricity for our environment, for consumers, and for the nation as a whole.

Plug-in vehicles have the potential to make an immediate difference in reducing air pollution and curbing dependence on oil. Over the long term, plug-ins can play a critical role in the effort to stop global warming. The technology needed to build workable plug-in vehicles exists today, but it will take a coherent strategy and concerted action in order to take full advantage of the potential of plug-in vehicles.

Plug-in cars can make a major contribution to America's efforts to reduce global warming pollution.

- More than 40 recent studies show that plug-in cars produce lower carbon dioxide than traditional gasoline-powered cars. One study by the Department of Energy's Pacific Northwest National Laboratory (PNNL) found that an electric car fueled by unused capacity in the current electric system would emit 27 percent less global warming pollution than a car fueled by gasoline, and would reduce global warming pollution in almost every area of the country, even where the primary source of electricity is coal.

- To take full advantage of the potential of plug-in vehicles, however, America must move toward a cleaner electricity grid. A study by the University of California, Berkeley Center for Entrepreneurship & Technology showed that if half of the light vehicles in the United States were electric vehicles powered by completely clean electricity in 2030, total fleet emissions would be reduced by 62 percent.

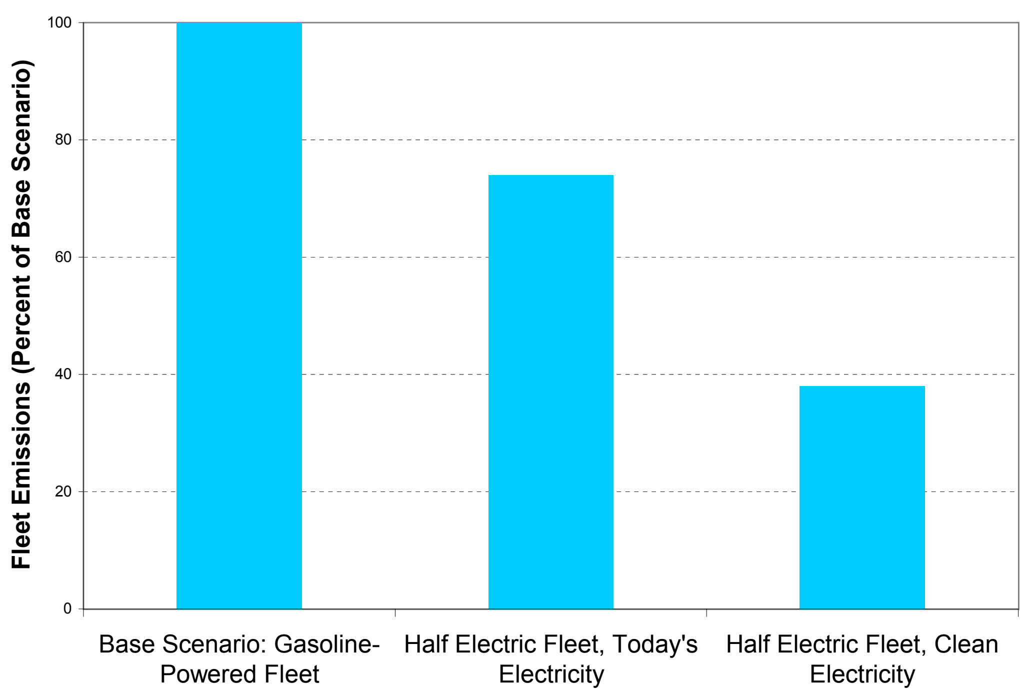
Switching to plug-in cars will improve air quality for most Americans.

- Replacing gasoline with electricity will reduce the smog found in our cities and other densely populated areas. The PNNL study found that powering a car on electricity would result in 93 percent less smog-forming volatile organic compound (VOCs) and 31 percent less nitrogen oxide (NOx) emissions than powering a car on gasoline.
- A study by the Electric Power Research Institute and the Natural Resources Defense Council found that, combined with our current emissions standards for power plants, converting 40 percent of U.S. cars to plug-in hybrids by 2030 would reduce smog for 61 percent of Americans, and increase it for 1 percent of Americans. Soot would decrease for 82 percent of the population, and increase for 3 percent of the population.
- Powering cars on clean electricity such as wind and solar power would virtually eliminate vehicle-related air pollution—whether from the tailpipe or the power plant.

Switching to plug-in cars will reduce oil consumption.

- A study by the Pacific Northwest National Laboratory found that if three-fourths of the cars, pick-up trucks, SUVs and vans in the United States were electric vehicles, oil use would be reduced by about one third.

Figure 1. U.S. light vehicle fleet global warming emissions under three different scenarios for fleet composition and fuel[1]



The technology for plug-in vehicles exists today, and plug-ins have several advantages over gasoline-powered cars.

- Plug-in hybrids that have been converted from conventional hybrids can achieve 100 miles per gallon or more.

- Electric cars that can go over 200 miles on one charge are being sold in the United States today.

- Most plug-in cars can charge in a normal wall outlet found in many home garages, and rapid chargers have been developed that can fill a 100-mile battery in under 30 minutes.

- Electric cars are much simpler to maintain than conventional cars, with few moving part compared with the hundreds of moving parts required for an internal combustion engine. Electric cars have no oil changes, and require far less regular maintenance.

Plug-in cars will be more expensive than gasoline-powered cars. However, operating costs of plug-in vehicles will likely be lower. And, over time, many factors will contribute to declining costs.

- The high incremental cost of a plug-in car is largely due to the cost of batteries. The National Renewable Energy Laboratory has estimated the near-term incremental cost of a plug-in hybrid to be about $10,000-27,000, depending on the size of the battery. In the long term, they predict the incremental cost will drop to $6,000-$13,000.

- Operating costs of plug-in cars are likely to be significantly lower than those of gasoline-powered cars. Electricity costs three to five cents per mile with average electric rates, or the equivalent of $0.75 to $1.25 a gallon of gasoline. Maintenance costs for fully electric cars will also likely be lower as electric vehicles are mechanically simpler than those with internal combustion engines.

- Plug-in vehicles could come with new models of ownership. Some companies, for example, could lease batteries to owners, eliminating the upfront cost of purchasing the battery and the potential cost of replacing it when it is no longer able to power a vehicle.

America's electric system has the capacity to fuel most of our cars today, but the nation will need to clean up our electric grid to reap the full potential of plug-in cars.

- A study by the Pacific Northwest National Laboratory found that America's electric system could fuel 73 percent of U.S. cars, pickup-up trucks, SUVs and vans without building another power plant, by charging vehicles at night.

- Utilities can structure electricity prices so that it is cheaper to charge cars at times of the day when there is lower electric demand, ensuring that a large number of plug-in cars do not put a strain on the utility. These rate structures will encourage plug-in car owners to use "smart chargers" that charge cars only when demand and electricity prices are low.

- With investments in "smart grid" technology, plug-in cars could help stabilize the electric grid and provide emergency backup power—reducing the cost of electricity for all consumers and making the grid better able to accommodate intermittent forms of renewable energy generation such as wind and solar power.

There are still barriers to the widespread adoption of plug-in cars, but smart public policy strategies can help to overcome those barriers.

- Despite rapid advances in battery technology, automakers and battery developers still have strides to make in arriving at battery designs that deliver the range and affordability American consumers are looking for. Continued **funding for research and development** of advanced batteries can help.

- The initial price of plug-in cars will likely be high, but getting significant numbers of plug-in cars on the road quickly is important to prove that the technology is viable and to identify unexpected hurdles. **Financial incentives** for buyers of the first generation of plug-in hybrids, coupled with policies to **encourage the purchase of plug-ins by government and private fleets**, can help get significant numbers of plug-in cars on the road quickly. So too, could a **low-carbon fuel standard** that allows plug-in vehicles to contribute to the goal of reducing life-cycle global warming emissions (including from indirect land-use impacts) from vehicle fuels by 10 percent by 2020.

- Unlocking the full environmental and economic potential of plug-in vehicles will require efforts to clean up and modernize America's electric grid. The United States should encourage the use of clean energy by adopting a **renewable electricity standard** requiring that 25 percent of our electricity come from renewable energy by 2025. The nation should further reduce global warming emissions from power plants by adopting a **cap on global warming pollution** that reduces emissions to 35 percent below 2005 levels by 2020 and to 80 percent below 2005 levels by 2050. Finally, the nation should invest in the adoption of **"smart grid"** technologies that would allow plug-in vehicles to help stabilize the grid.

- The lack of public charging infrastructure—while not a deal-breaker for plug-in vehicle owners who can charge their cars at home—could limit the willingness of some consumers to buy or use plug-in vehicles. Local, state and federal governments should jump-start the creation of charging infrastructure by installing chargers at publicly owned facilities, developing procedures for the installation of chargers on city streets, and providing incentives for private development of charging infrastructure.

Introduction

The 20th century was the age of the automobile. But as the last century began, it was still unclear just what fuel would power the new age.

In 1900, steam-powered and electric vehicles competed with internal combustion engine cars for dominance of the new market. Engineers, inventors and weekend tinkerers worked to come up with new technologies to improve the safety, range and reliability of cars. Eventually, the combination of better technology, access to a cheap, powerful and plentiful fuel (oil), and the successful mass production of internal combustion vehicles led to gasoline-powered vehicles becoming the dominant force in the car market.

Fast-forward to the early 21st century, and the age of the internal combustion automobile appears to be on the wane. Oil is no longer cheap or plentiful. America's Big Three automakers—long wedded to a business model that relied on the sale of large, gas-guzzling vehicles—are on the ropes. Environmental challenges, from air pollution to global warming, are driving more Americans to look for cleaner transportation alternatives. And for the first time in decades, a new type of automobile power plant—the hybrid-electric vehicle—has gained a foothold in the marketplace.

Now, in a reprise of the frenetic experimentation and entrepreneurial zeal of the early 20th century, the race to develop the car of the 21st century is on. Silicon Valley entrepreneurs, Big Three automakers, academics, government researchers, battery manufacturers, engineers from Detroit to Beijing to Mumbai—all of them are working to develop a car that is affordable, reliable, doesn't rely on oil, and can contribute to reducing global warming pollution.

As was the case a century ago, there are many candidates for the "car of the new century." Hydrogen fuel-cell cars and cars that run on various types of alternative liquid fuels are among the possibilities. But perhaps the most promising candidates are "plug-in" vehicles—those that can be fueled, either entirely or in part, by electricity from the grid.

Plug-in vehicles have many advantages. They are energy efficient. They produce no tailpipe pollution when operating on electricity. There is already a vast electric power infrastructure in existence to fuel them. And they can be powered with clean, renewable energy, making them a potential solution to the challenge of global warming.

But, as with any technological innovation, there are many questions about plug-in vehicles. What will they be like to drive? How will we fuel them? Can the electric system stand up to the strain of providing power for our cars? And are they really good for the environment?

This white paper addresses many of the questions about plug-in vehicles and lays out a strategy for how public officials can both help bring this exciting technology to more Americans and ensure that plug-in vehicles make the maximum possible contribution to addressing our nation's environmental and energy challenges.

Plug-In Cars: What Are They and Why Are They Important?

The term "plug-in" refers to any car that has both an electric motor and a battery that can be charged externally. A **plug-in hybrid** is a car with both an electric motor and an internal combustion engine. Plug-in hybrids are similar to conventional hybrids, except that they have larger batteries that can be charged externally, allowing them to achieve in the range of 100 miles per gallon of gasoline. **Electric cars** run entirely on electricity, with no internal combustion engine.

Plug-in cars have several advantages over gasoline-powered vehicles. They produce less global warming pollution, emit little or no pollution from the tailpipe, and reduce our dependence on oil. Battery-powered vehicles also have practical and environmental advantages over many other types of alternative-fuel vehicles.

While plug-in cars are not yet cost-competitive with gasoline-powered vehicles and the technology still needs improvement, they are ready today for consumers who are eager to drive low emission cars.

Plug-In Hybrids

Hybrid cars are cars that have both an internal combustion engine and an electric motor. The batteries in today's hybrid vehicles are charged by the vehicle's gasoline engine and by energy recovered from braking. In a conventional hybrid, the battery is used to boost the internal combustion engine as the car is driven, and allows the car to go farther on the same amount of gas.

Plug-in hybrids also have the ability to draw power from the electric grid. To store this additional electricity, plug-in hybrids have larger batteries than conventional hybrids. Plug-in hybrids can generally be charged from a standard home outlet. At the same time, plug-in hybrids have an internal combustion engine that can power the vehicle on longer trips that are beyond the range of the vehicle's battery.

Not all plug-in hybrids are alike. One key difference is in vehicles' "all-electric range"—the distance they can travel on electricity alone. Some plug-in hybrids are closer to today's conventional hybrids—they can go only a few miles on battery power alone before reverting to gasoline power. Others are closer to electric vehicles—they can go 40 miles or more on a charge, meaning that the internal combustion engine is rarely used in daily driving. There is a trade-off for higher all-electric range, however—the vehicle must carry more batteries, which results in higher cost.

Another difference among plug-in hybrids is in the role played by the internal combustion engine versus the electric motor. In parallel hybrids, like the Toyota Prius, the wheels are connected to both the electric motor and the internal combustion engine. In series hybrids, the car is propelled solely by its electric motor, and the internal combustion engine produces electricity to recharge the battery.

In addition, there are variations in the ways plug-in hybrids can deploy gasoline and electric power. Plug-ins may operate in "charge depleting" mode, in which the battery is used as the primary source of energy until it becomes depleted, when gasoline takes over as the primary source of energy for the vehicle. Many vehicles operating in charge-depleting mode may rarely need to use the internal combustion engine. The majority of car trips are less than 25 miles, so a typical owner of a plug-in hybrid with a 40-mile electric range that only switches to gas when its battery is drained will rarely need to refill its gas tank.[2] Many plug-in hybrids being developed today, such as the Chevy Volt, are designed to operate in charge-depleting mode.

On the other hand, plug-in hybrids may also be designed to operate in "blended" mode, in which the combustion engine provides an assist for the electric motor when it is most needed—even if there is charge remaining in the battery.[3] These plug-in hybrids would operate in a manner similar to some of today's conventional hybrids, in which the vehicle accelerates to a certain point on electric power alone, after which the gasoline engine kicks in. A plug-in hybrid operating in blended mode can get greater range out of a battery, but with the sacrifice of using gasoline and producing emissions even at times when there is charge remaining in the battery.

While there are currently no mass-produced plug-in hybrids on the road, many conventional hybrids have been converted into plug-ins operating in blended mode, with notable—though greatly varying—benefits for fuel economy. Seattle converted over a dozen of its Toyota Prius hybrids to plug-in cars, and over the first year they averaged 51 miles per gallon.[4] However, Google tested a fleet of plug-in hybrids that got an average of 93.5 miles per gallon.[5] Future plug-in hybrids operating in charge-depleting mode will have more consistently high gas mileage.

Electric Vehicles

Electric vehicles use only electric power. Despite their high-tech reputation, electric cars have been produced for more than a century, with early electric cars losing out to the gasoline-powered Model T for dominance in the early days of the automobile industry.[6] Today, we continue to have electric vehicles in the form of golf carts and fork lifts. A few fully electric cars have also been sold to consumers, such as the Toyota RAV4-EV.

The main difference between electric cars and conventional gasoline cars is under the hood. A simple electric motor replaces the internal combustion engine, eliminating the need for oil changes and some other forms of routine engine maintenance. There is no tailpipe pollution from an electric vehicle because there is no tailpipe. Power for the vehicle is drawn from banks of batteries, which are recharged through a connection with the electric grid.

The main technological hurdle to electric vehicles has been their batteries. A gasoline tank stores a tremendous amount of energy in limited space and can be refilled in minutes. By contrast, batteries tend to be much heavier and larger for the amount of energy they store and take longer to recharge. They also have limited lifespans and are more expensive.

In recent years, advances in battery technology have increased the amount of energy that can be stored, reduced their cost, and extended their lifetime.[7] As the number of products that use advanced batteries—from cell phones to laptops—has grown, so has the amount of research and investment in advanced battery technologies. The lead-acid batteries that have dominated the car market for decades are now being superseded by the nickel metal hydride batteries used in today's hybrid cars, and may soon be surpassed by lithium-ion batteries.

Along with advances in battery technology, fast-charging technology has also improved. Extremely fast chargers for electric cars exist, and a network of chargers that could allow electric car owners to take their cars on longer trips would make it more convenient to own an electric car.

Why Use Electricity as a Fuel?

Electricity is an attractive option for fueling cars because of its potential to reduce global warming emissions and other pollution, and because, in contrast to other types of alternative fueled vehicles, such as hydrogen, the technology can be applied today. Electricity has been used to power transportation since the early 1900s, and the infrastructure for delivering electricity to cars largely already exists.

Indeed, limited numbers of fully electric vehicles have traveled America's roads for two decades. In the 1990s, the General Motors EV1 and Honda EV-Plus were sold in California. While they were expensive and had limited range, they drew rave reviews from their owners due to their quiet operation, quick acceleration, easy maintenance and environmental friendliness. In the early 2000s, Toyota sold the RAV4-EV in California, with a range of about 100 miles and a price tag of $42,000.[8]

Electric cars have lower global warming emissions and produce less air pollution than conventional cars. Electric motors are vastly more efficient than internal combustion engines. Out of all of the energy produced when a car burns gasoline, only 13 percent actually goes towards moving the car forward.[9] An electric car is about twice as efficient, with about 24 percent of the energy in the fuels consumed at a power plant actually going toward powering the car.[10] Therefore, even if the electricity used to power a vehicle comes from relatively dirty sources, electric cars still produce less global warming and air pollution than conventional cars. With the very dirtiest electricity, electric cars are about equivalent to today's conventional cars in terms of global warming pollution.[11] With cleaner electricity, such as that produced by wind or solar power, the difference in pollution emissions is far greater. (See page 11 for more detail).

Another advantage to electricity—especially when compared to fuels such as hydrogen or biofuels—is that we have already built a system for production and distribution of the fuel. Even the most remote areas of the United States have access to a power line—and those few that do not still have the ability to generate electricity from solar power or other local renewable sources.

Other alternative fuels fail to match the promise of electricity as a long-term solution—either for technological or environmental reasons. Hydrogen fuel, while it too can be created from renewable sources, faces many of the same energy storage challenges as electricity—and would require the construction of a vast new network of production facilities and filling stations. Biofuels such as ethanol and biodiesel can be used in existing internal combustion engines, but have mixed impacts on the environment, are unlikely to be produced in enough quantity to fuel the nation's vehicles by themselves, and require their own new investments in infrastructure. Natural gas is lower emitting than gasoline, but still contributes to global warming and, again, requires the construction of new fueling infrastructure to become a practical, everyday alternative.

Electricity can also be used in tandem with other alternative fuels to maximize their benefits. Plug-in hybrids operating on low-emission biofuels, for example, could displace vast amounts of gasoline consumption while reducing the amount of biofuels that must be produced.

The remaining hurdles to widespread use of electricity as a vehicle fuel, while real, are not so large as to prevent the initial roll-out of plug-in vehicles. Plug-in hybrid and electric vehicles already travel America's roads, are already capable of delivering environmental benefits, and can already be fueled using infrastructure found in virtually every part of the country. Future improvements that would unlock the full potential of plug-ins—such as movement toward lower carbon sources of electricity, the creation of a more interactive electric grid, and the expansion of infrastructure for vehicle charging—while important, can therefore be implemented gradually over time.

In sum, plug-in vehicles—whether fully electric or hybrids—are already technologically practical alternatives to gasoline-powered vehicles, with great potential to address the nation's environmental challenges and our dependence on oil.

Mike Kane and Cathy Lam and their children with their Toyota RAV4-EV, a completely electric vehicle that goes over 100 miles on a charge. They bought the car in 2003, and reached the 100,000 mile mark in 2008. Mike and Cathy power their car with solar panels on their house. Photo credit: Mike Kane.

Plug-Ins and the Environment

Plug-in cars are generally better for the environment than conventional cars. They produce less global warming pollution, fewer emissions of other air pollutants, and use far less oil.

The size and scope of the benefits America would receive from plug-in vehicles depend, however, on how we generate the electricity to supply them. If we clean up the electric grid by reducing our use of polluting energy sources and increasing our use of clean energy sources such as wind and solar power, we can maximize the environmental benefits of plug-in vehicles.

Global Warming and Plug-Ins

Plug-in cars emit less global warming pollution than cars powered by gasoline when fueled from today's electricity sources. This is largely because electric motors are vastly more efficient than the internal combustion engine, driving a car much farther on the same amount of energy.[12]

Many studies have compared global warming pollution from plug-ins versus that from conventional cars. There is a wide range of results, since there are a number of factors that differ from study to study—for example, the gas mileage of the conventional cars plug-ins are being compared against, and the amount of electricity the plug-in cars are assumed to use. However, over 40 recent studies have shown that plug-in cars produce less carbon dioxide than traditional gasoline-powered cars.[13]

An electric car powered by electricity from today's electric grid will have lower global warming emissions than a conventional car. One study by the Pacific Northwest National Laboratory (PNNL) found that a car fueled by electricity from unused capacity in our current electric system would emit 27 percent less global warming pollution than a car fueled by gasoline.[14]

The environmental benefits of plug-ins depend on the source of electricity used to power them. Because some parts of the country are heavily reliant on coal—which produces large amounts of global warming pollution—and others use cleaner sources of energy, the benefits of plug-ins vary from state to state and region to region. Even with this variation, the PNNL study found that global warming emissions per mile driven by an electric motor would be lower in every area of the country except for the Northern Plains states, where emissions would stay the same.[15]

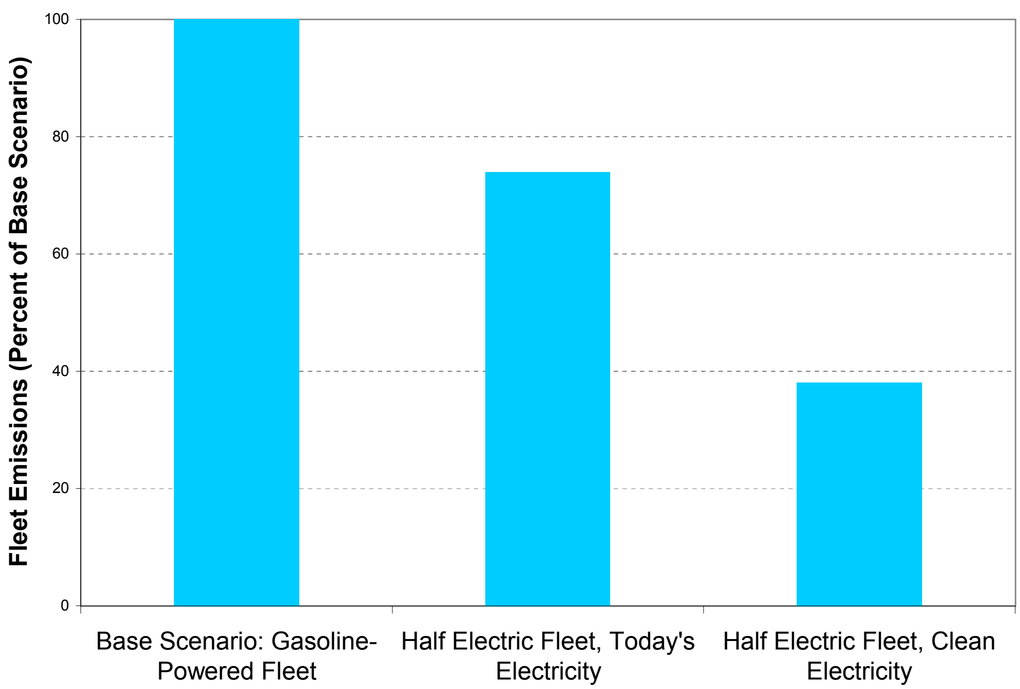
In other words, cars driving on electric power deliver roughly the same level of global warming emission reductions as today's conventional hybrids—with greater reductions in areas of the country with a cleaner electric grid and smaller reductions in areas with a dirtier grid. So why bother with a new technology that is (for the time being at least) more expensive than today's hybrids?

The reason is that plug-ins are among the few technologies capable of producing dramatic reductions in global warming pollution from vehicles over the long term. Plug-ins can achieve that potential if they draw their power from a clean electricity grid, or from solar panels on rooftops or parking lots.

A study by the University of California, Berkeley Center for Entrepreneurship & Technology showed that having clean electricity sources would increase the global warming emission reductions from plug-in cars. The study found that if about half of the U.S. fleet were powered by clean electricity in 2030, total fleet emissions would be reduced by 62 percent—compared with a fleet powered with high-priced gasoline and with an average fuel economy of 35 miles per gallon. By contrast, if the same electric vehicles were powered by electricity from the 2007 U.S. grid, fleet emissions would be reduced only 26 percent.[16] (See Figure 2).

In fact, beyond just utilizing clean

Figure 2. U.S. light vehicle fleet global warming emissions under three different scenarios for fleet composition and fuel[17]



"Base scenario" assumes an average fuel economy of 35 miles per gallon and high gasoline prices; "half electric fleet" is 46 percent of the current U.S. fleet powered by electricity; "today's electricity" is power from the 2007 electric grid; "clean electricity" is electricity with zero global warming emissions.

energy, plug-in cars could actually make it easier to increase the amount of clean energy in the United States. With the implementation of smart grid technology, the storage capacity in plug-in cars could be tapped to smooth out the intermittency of renewable energy sources such as wind and solar power. (See page 16 for more detail.) By expanding the grid's ability to accommodate renewable sources of energy, plug-ins could contribute to reducing global warming emissions in the United States even when they are parked.[18]

Air Quality and Plug-Ins

Switching to plug-in cars would improve air quality for most people in the United States. If the nation continues to rely on coal-fired power plants, emissions may rise for some people who live near those plants. But enforcing stringent air pollution standards for power plants and increasing the amount of clean electricity would reduce that threat and ensure that a switch to plug-in cars would improve air quality for everyone.

Plug-in cars produce less tailpipe pollution than conventional cars, but fueling them with electricity from our current energy sources will increase air pollution from power plants. A study by the Department of Energy's Pacific Northwest National Laboratory found that powering a car with electricity would result in 93 percent less smog-forming volatile organic compounds (VOCs) and 31 percent less nitrogen oxides (NO_x) than powering a car with gasoline power, including power plant emissions.[19] Further reductions would likely occur if polluting sources of electricity generation were to be replaced with cleaner, renewable sources.

These estimates assume, however, that we would use existing coal-fired power plants, as they are, to supply the extra electricity for our cars. While coal plants will always be dirty, technology exists that limits the amount of soot and smog they produce. Power plant emissions of NO_x and SO_x are limited by a national cap-and-trade program which reduces some power plant emissions over time. As the number of plug-in cars increases over time, our electric grid will continue to become cleaner in regards to air quality as long as we enforce and strengthen the laws that we have in place.

A study by the Electric Power Research Institute (EPRI) and Natural Resources Defense Council (NRDC) showed that using plug-in cars will improve air quality beyond the large emissions reductions that will already result from current laws. The study found that if 40 percent of the vehicles on the road were plug-in hybrids in 2030, VOC and NO_x emissions would be reduced by over 1.5 percent, compared with continuing to use conventional vehicles. Sulfur oxide (SO_x) emissions would not rise or fall compared with business as usual.[20]

Pollution from power plants can have serious impacts on nearby communities, as well as the environment as a whole. But fossil fuel-burning power plants tend to be located in less populated areas, whereas automobile pollution is greatest in the midst of densely populated urban areas. As a result, when weighted for population, the clean air benefits of plug-ins are even more significant. The EPRI and NRDC study found that if 40 percent of the vehicles on the road were plug-in hybrids in 2030 and current power plant pollution laws were enforced, smog levels would decrease for 61 percent of the population, and increase for 1 percent of the population. Soot would decrease for 82 percent of the population, and increase for 3 percent of the population.[21]

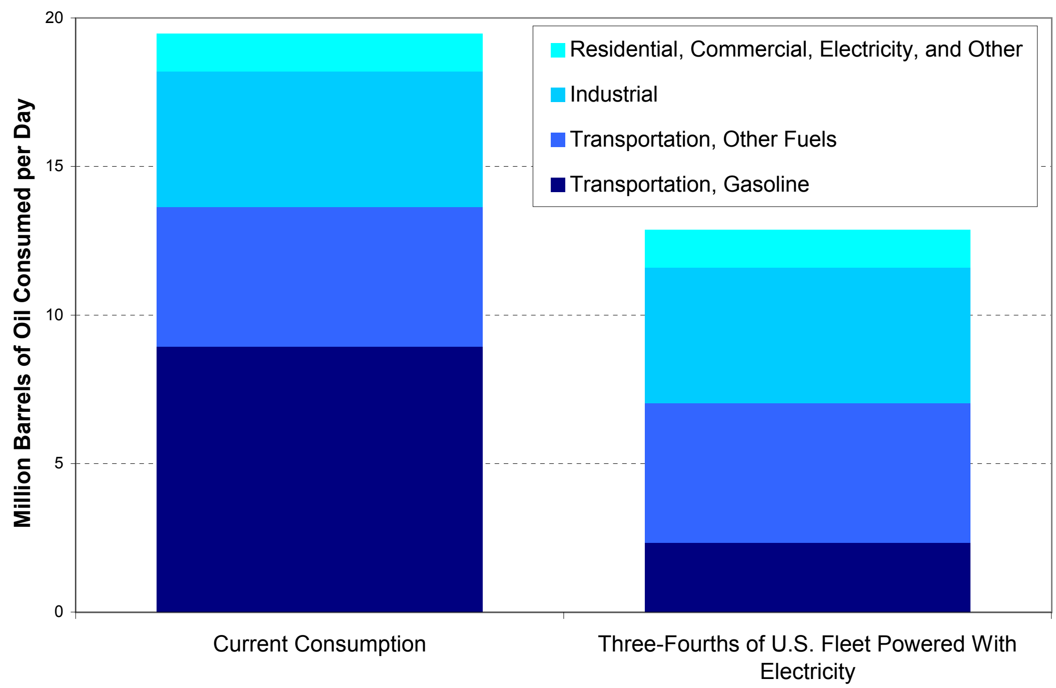
As plug-in vehicles make up an increasingly large percentage of our cars, it will be critical to enforce our power plant emission controls to ensure that improvements in air quality for many are not at the expense of others' health.

Increasing the amount of clean energy in our electricity supply would improve air quality even further. Studies of the effect of plug-in cars on air quality tend to assume the status quo for our energy sources, leading to projections of high increases in the amount of coal supplying our electricity over the next few decades. Committing instead to get more of our electricity from clean sources such as wind and solar power would improve air quality significantly. And as discussed above, widespread use of electric cars will make it easier to increase the amount of clean energy in our grid, leading to decreases in air pollution from both cars and power plants.

Plug-Ins and Oil

Switching to plug-in cars will significantly reduce our dependence on oil. Two-thirds of the oil used in the United States is used for transportation.[22] By using electricity rather than gasoline to power vehicles, plug-in vehicles can significantly reduce our dependence on oil. A study by the Pacific Northwest National Laboratory found that if three-fourths of the cars, pick-up trucks, SUVs and vans in the United States were powered by electricity, oil use would be reduced by about one third, and gasoline use would be reduced by about three-fourths (see Figure 3).[23]

Figure 3: Oil savings from powering three-fourths of the U.S. light vehicle fleet with electricity[24]



Will the Electric Grid Be Able to Handle Plug-In Cars?

America's existing electric system has enough capacity to supply power to most of the current fleet of cars in the United States if they were plug-in vehicles. If plug-in cars are charged at night, they could take advantage of unused capacity in the system—and potentially do so at lower prices. Even if most cars are charged during the day, it will be a long time before there are enough plug-in cars to be a strain on the system. To take full advantage of the potential of plug-in vehicles, however, American will need to move toward a cleaner electric grid.

If America pushes forward with plans to build a "smart grid," plug-ins could even help the electric system work better. "Vehicle-to-grid" (V2G) technology would make it possible for utilities to use the storage capacity in the batteries of parked cars to make the grid more reliable. In a V2G system, utilities would compensate plug-in car owners for the use of their batteries, and set up systems that would ensure that the cars are fully charged when their owners need them. The large amount of electricity storage capacity that plug-in cars would provide could make it possible to use more wind and solar power than our grid can currently support.

Supplying the Electricity for America's Cars

The current electric grid could handle a significant portion of U.S. cars running on electricity, especially if they're charged at times of the day when electricity demand is low. Even if cars are charged during times of high demand, the gradual introduction of plug-in cars will not put a large strain on our electric system.

America's electric system is designed to supply reliable power under all conditions. That means that the nation must have enough power plants and transmission wires to provide power for the few hours each year—usually during summer heat waves—when electricity consumption peaks. Most of the time, however, there are vast amounts of unused capacity in the system. This extra capacity is enough to fuel 73 percent of the cars, SUVs, pickup trucks and vans in the United States as plug-in hybrids without adding a single additional power plant.[25]

The times when there is the most extra capacity in the electric system also happen to be the times when most Americans will charge their plug-in vehicles—at night. Utilities could encourage nighttime charging by providing lower, off-peak electric rates during those hours, as some utilities already do. Drivers could also use a controller for their home charger—a "smart charger"—that would start charging the car at the time that rates drop, so they wouldn't have to worry about what time they plug the car in.[26] Lower electric rates would add to the cost savings of electricity versus gasoline as a vehicle fuel.

Widespread nighttime charging, however, can have environmental disadvantages. Currently, the grid is served at periods of low demand by power plants with low costs of operation—either "baseload" sources such as nuclear energy or intermittent sources such as wind or hydroelectric power for which there are no fuel costs. The next set of power plants utilities run to supply additional demand are those powered by low-cost fuels, particularly coal, followed by those operating on higher-cost fuels such as natural gas.

The environmental impact of adding a plug-in hybrid to the nighttime grid depends on the type of generator that would be "switched on" to meet the additional demand, which will vary depending on the local mix of resources. If the additional demand is met through increased generation at coal-fired power plants, the pollution benefits of plug-ins could be much reduced, though plug-ins would likely still produce less carbon dioxide pollution than conventional vehicles.[27] If, on the other hand, the additional demand is met through renewable energy resources available at night—such as wind power—the impact on emissions will be far smaller.

The adoption of plug-in cars will be gradual, so even if they were usually charged during times of peak demand, they would not be a big strain on the electric grid in the short term. A study by the National Renewable Energy Laboratory found that 1 million plug-in cars charging simultaneously would only use about 0.16 percent of our current electricity capacity.[28] As an increasing number of drivers are plugging in their cars, smart chargers will become more necessary to ensure that utilities can manage the increased use, and to prevent local electric infrastructure from being overloaded.[29]

In short, there is ample electricity capacity to serve plug-in vehicles in the near term. By moving toward a cleaner electric system that uses more renewable energy, America can also ensure that plug-ins deliver the maximum environmental benefit.

Plug-Ins as a Grid Asset

Plug-in vehicles draw power from the electric grid, but they can also supply power to the grid, acting as a valuable asset to the smooth functioning of the electricity system. Using "vehicle to grid" (V2G) technology, utilities could use the energy stored in plug-in car batteries to stabilize the grid, avoiding the need to pay for expensive backup and peak generators. By compensating drivers for the use of plug-ins for reliability purposes, utilities could reduce the lifetime cost of a plug-in car.

As mentioned above, utilities must design the electric system to function under any conditions. That means building a system large enough to supply power during the few hours each year when consumption is at its peak and having enough backup resources on hand to provide power in case of unexpected problems.

Today, peak and backup power are supplied by generators, usually burning fossil fuels. Depending on their function, these generators are only used a small fraction of the time or only supply a small amount of power.[30] That makes them extremely expensive to maintain and operate, with those costs passed on to electricity consumers.

If utilities could store power, rather than having to match generation to demand on a second-by-second basis as they do now, they could do away with much of the expensive peak and backup generators they must currently maintain, with big potential savings to consumers.

The millions of plug-in car batteries that would be attached to the grid could serve as that source of electricity storage. Most cars are parked over 90 percent of the time, and therefore capable of supplying extra power to the grid.[31] With V2G technology, plug-in car owners could contract with utilities to let them use their batteries when the cars are plugged in.

Plug-in batteries could serve several valuable functions for utilities. The first would be providing small amounts of power or storage capacity to respond to second-to-second changes in demand. When demand rises, utilities could pull small amounts of electricity from full batteries; when demand drops, utilities could send extra electricity to batteries that aren't full.[32]

The second function would be providing backup power in case something goes wrong at a power plant. This will likely only happen about 20 times in a year, for 10 minutes to an hour, but utilities need to have backup power that can be quickly available all the time. Instead of using generators, utilities could pull from car batteries plugged into the grid when these failures happen.[33]

The third function would be to serve peak demand in the system. During the hot summer months, for example, a vehicle could be charged at night, and then discharge to the grid during the day, reducing the need to fire up expensive and polluting peak generators.

These services would be extremely valuable to utilities, with an estimated value of as much as $4,000 per year per car.[34] Passing even a fraction of those savings along to vehicle owners would go a long way toward making plug-in vehicles an economical alternative.[35]

The batteries of plug-in vehicles also provide a resource that can be used to expand the use of intermittent sources of renewable energy such as wind and solar power. Again, because electricity supply and demand must be in perfect balance every second of the day, utilities must ensure that they have enough generation capacity on hand to meet demand even when the sun isn't shining or the wind isn't blowing. The U.S. electric grid can handle much more wind and solar power than we have today, but by using plug-in vehicles to supply power at times of low solar or wind energy production, the nation would be able to dramatically expand its use of renewable energy without affecting the reliability of the grid. One study published in the Journal of Power Sources found that if 26 percent of our cars were plug-ins using V2G technology, our electricity grid would be able to get a fifth of its electricity from solar power at the height of the day.[36]

Having plug-in vehicles available using V2G technology would not only allow utilities to use more wind power, but it would also reduce the cost of expanding wind power, by eliminating the need to purchase backup power. The same study found that if about 40 percent of the cars in the United States were electric cars using V2G technology, we would be able to get half our electricity from wind power.[37] A study by the National Renewable Energy Laboratory found that if half our cars were plug-in hybrids using V2G technology, market forces alone would double the amount of wind power in the United States by 2050.[38]

V2G technology is appealing, but still far away. V2G technology will require that utilities are able to have two-way communication with power outlets and car chargers. Upgrading the electric system to have "smart grid" capabilities would allow plug-in car owners to take advantage of the potential to earn some money through their cars, and would make it possible for utilities to get more electricity from wind and solar power.

For now, however, plug-in car owners and utilities will be able to take advantage of the storage capacity available in plug-in cars even before the electric grid is upgraded through "vehicle to home" technology, or V2H. In this system, drivers can use stored electricity in their car batteries to power their homes.

For example, a driver going to work could park his or her car in a parking lot outfitted with solar panels. The solar panels could charge the vehicle during the day, powering the commute home and leaving enough energy to power the home during the high-demand evening hours. Then, at night, the vehicle could be recharged with wind power from the electric grid. Drivers who stay home during the day could charge their cars on cheaper power at night and, when not planning long drives, could use extra battery capacity to power their homes during the day.

V2H provides many of the benefits of V2G, but consumers and utilities will be able to take advantage of it with the current electric grid without waiting for upgrades. V2H allows drivers to benefit from lower electricity rates at night, and to have more control over the sources of electricity their homes are using. With V2H, utilities do not have control over the car's charging, but benefit when consumers use less peak electricity, which they can encourage by charging less for electricity used at night.[39]

With "vehicle to home" technology, plug-in car owners could charge their cars during the day at solar parking lots—such as this one at Kyocera's employee parking lot in San Diego, California—then use remaining battery power after they drive home to help power their houses in the evening. Photo credit: Envision Solar.

Owning a Plug-In Vehicle

Owning and driving a plug-in car will be similar to driving a conventional car, but different in a few key ways. For all plug-in vehicles, charging up the vehicle will reduce or eliminate the need to visit gas stations. Most plug-in cars can use a standard wall outlet, found in many garages, and will gain enough battery charge overnight to fuel a typical day's driving. Taking a fully electric car on a long road trip will require infrastructure for quick charging or battery changing that is not yet in place, but the technology exists to make recharging a car relatively quick and easy.

The economics of owning plug-in cars will be different than those of conventional vehicles. They will cost more up-front—a great deal more in the near term while the market is immature and technology is developing—but will be cheaper to fuel and possibly cheaper to maintain. Plug-in cars will be quieter and smoother to accelerate and drive than conventional cars, and will require less maintenance. They are just as safe as conventional cars, both in terms of crash safety and the safety of the battery as compared with gasoline.

Driving a Plug-In Car

Plug-in vehicles have several performance advantages over conventional vehicles. They are generally quieter, quicker to accelerate, and easier to operate. And fully electric vehicles offer the potential for design flexibility that could radically alter the driving experience.

The most obvious difference in the cockpit of a fully electric vehicle (or a series plug-in hybrid) is what is missing. There is no need for a clutch, a gear shift or a transmission. Also missing is noise; electric motors are much quieter than internal combustion engines, an effect that can already be seen in today's hybrids.

Electric vehicles also offer quicker and smoother acceleration. Electric motors generate their maximum torque at standstill and provide instantaneous power, meaning that there is none of the hesitation involved in waiting for an internal combustion engine to get up to speed. As a result, electric vehicles can post impressive acceleration times—the all-electric Tesla Roadster, for example, goes from zero to 60 mph in four seconds.[40] Electric vehicles also slow quickly once the motor is turned off, meaning that there is little need for aggressive braking.[41]

The simplicity of electric vehicles means that fully electric cars will be much easier to maintain. Gone are the hundreds of pistons, cylinders, pumps, valves, and other parts in an internal combustion engine.[42] Gone, too, as described above, are the clutch, transmission and gearbox, as well as the exhaust system. Oil changes will be unnecessary. The result is that the routine maintenance that adds to the cost and inconvenience of owning an internal combustion vehicle will be dramatically reduced.

The one potential big-ticket maintenance expense unique to hybrid and plug-in vehicles is the need to replace batteries. A battery for a plug-in vehicle can cost more than $10,000, so avoiding the need to buy a replacement battery is critical for ensuring the financial viability of plug-in cars.

Battery life could be a more significant hurdle to plug-in hybrids than to today's conventional hybrid vehicles, since plug-in vehicles will be much more reliant on their batteries than today's hybrids, with deeper discharging of the batteries eroding battery life.[43] But the experience to date with hybrid vehicle batteries provides hope that the issues surrounding battery life can be resolved. Despite initial fears about the lifespan of the batteries used in today's hybrid vehicles, battery replacement has not been an issue for hybrid drivers. Hybrid car batteries were originally warrantied for eight years, but Toyota claims that none of its batteries, now almost 10 years old, have worn out—those replaced have been in cars involved in accidents. This includes some cars that have been driven over 200,000 miles.[44]

The simplicity of electric power systems will also allow a much greater variety of car styles. Electric motors are smaller than internal combustion engines and the location of the engine and batteries in the car is fairly flexible.[45] As a result, automobile designers will have much more flexibility to improve aerodynamics, reconfigure interior space, or develop unique cosmetic packages.

Staying Charged

Charging up a plug-in car is not rocket science. Today, plug-in cars can be charged at home overnight, using a standard connection to the electric grid. Over the long term, infrastructure to charge cars away from home will add to owners' options.

Many plug-in hybrid owners will likely charge their cars overnight from a normal wall outlet. Most plug-in hybrids, such as today's converted Priuses, can be charged from a standard wall outlet in about five to nine hours.[46] A majority of America's housing units already have a garage and others have electric outlets that would be easily connected to a plug-in car.[47] Some drivers may want to install a 220-volt outlet in their garage, like the type installed for an electric clothes dryer, to charge the battery more quickly, but for most this won't be necessary.

For drivers without a garage or off-street parking, charging will be more of a challenge, but on-street charging stations are already in place in several cities, and the technology for extending electric power to the curbside is not complex; similar systems are already in use at marinas and campgrounds.

Most drivers will charge fully electric vehicles in the same way. Although an electric car's battery is larger than that of a plug-in hybrid, charging time depends on the amount the battery is depleted. A typical car owner drives under 25 miles a day, requiring only a few hours of recharging, which can happen overnight.[48] Electric vehicles will likely come with a faster charger that can fill a car's battery in much less

On-street car chargers, like this one in San Francisco, will make it easier for people who don't have off-street parking to own plug-in cars. Photo credit: Siena Kaplan.

time, which will be useful when the car's battery is fully depleted.

If a family is relying on an electric car as their primary vehicle and using it for long trips, they will need a way to recharge the car on the road. Electric cars today have a range of about 100-200 miles, although this may increase as battery technology develops.

One option that would allow electric car owners to take their cars on long trips is to install fast chargers at gas stations or along highways, which would allow drivers to recharge their cars when they stop for a meal or at a rest stop. Extremely fast chargers already exist that can fully charge a battery with 100-mile range in under half an hour.[49] Fast chargers have been installed in some places in the United States, such as Hawaii. Washington, D.C. has partnered with AeroVironment, a leading producer of charging stations, to install hundreds of fast chargers throughout the city.[50] This network can be developed over time as an increasing number of drivers own plug-in cars.

Another plan would change batteries instead of charging them for quick refueling. One company, Better Place, has a business plan in which the company would own batteries and lease them to owners of compatible electric cars. The batteries could be charged at charging stations around a city, or changed at battery changing stations along highways. This would make owning a fully electric car easier in a few ways—leasing batteries instead of owning them would bring down the initial sticker price of the car, and battery changing could happen even faster than with quick chargers, in under two minutes, eliminating concern about vehicle range.[51] It would also eliminate concerns about battery lifetime, and enable consumers to have new and improved battery technology quickly, instead of waiting until they buy a new car. A company providing electricity to fuel a large network of cars may be better positioned to negotiate with utilities to deploy V2G charging, or to supply its own clean electricity through solar arrays or wind turbines at charging stations.[52] On the other hand, electric car owners leasing batteries might not benefit from the lower fuel prices usually associated with electric cars, unless gas prices rise dramatically.[53]

Investments in infrastructure for alternative fuel vehicles often fall prey to a "chicken and egg" problem—investors are unwilling to invest in new infrastructure if there are not cars on the road to use it, while potential car buyers are unwilling to purchase an alternative fuel vehicle if there is nowhere to fuel it. Because many early drivers of plug-in cars will be able to recharge at home, the need for extensive charging infrastructure is less acute. However, government will still need to take action to encourage the development of charging or battery-swapping infrastructure while the plug-in vehicle market is developing.

In many ways, though, the focus on the limited range of fully electric vehicles is misplaced. Americans have become accustomed to using one type of vehicle for all their transportation needs and having only one option for fueling it. Electric vehicles can meet most of the driving needs of most of the American public today, without extensive new charging infrastructure. For those Americans who take frequent, longer trips, plug-in hybrids or even conventional hybrids (perhaps operating on alternative fuels) remain options. For two-car households, an electric vehicle can be used for city driving and a plug-in hybrid for longer trips. Other transportation options—including trains, planes, and rental cars—can help fill the gaps for longer trips. In short, the limited range of electric vehicles need not be a "deal breaker" for their adoption by a large share of the American public.

The Cost of Owning a Plug-In Car

Plug-in cars cost more than conventional vehicles, but those higher up-front costs are mitigated by lower fuel and maintenance costs. Because they are a relatively new technology, and are produced in small quantities, plug-in cars are much more expensive today. However, technological advances and mass production should bring prices down, making them competitive with today's conventional vehicle technology.

Today's conventional hybrids can be converted to plug-in hybrids for a total cost of about $30,000-$35,000 depending on the hybrid, with a $1,000 federal tax rebate.[54] Previous and expected prices of plug-in cars sold as such are in the range of $40,000-$50,000. General Motors has said that the Chevy Volt, a plug-in hybrid scheduled for release in late 2010, will cost about $40,000.[55]

In the long term, when plug-in cars have been on the mass market for a number of years and no longer have the cost premium associated with new technologies, their upfront cost will be much lower. The National Renewable Energy Laboratory has estimated the near-term incremental cost of a plug-in hybrid to be about $10,000-$27,000, depending on the size of the battery.[56] In the long term, they predict the incremental cost to drop to $6,000-$13,000.[57] A123, a leading battery manufacturer for plug-in cars, more recently estimated that by 2012, the price of a lithium-ion battery for a fully electric car will be about $11,000.[58]

Even a $6,000 cost premium sounds like a lot of money. But it is easy to forget that much of the cost of today's internal combustion vehicles is not paid to the car dealer—rather, it is accumulated over time in gasoline and repairs. According to the American Automobile Association (AAA), gasoline and maintenance expenses account for 14.6 cents of the 54 cents per mile in costs incurred by the driver of an average automobile—or just over one quarter of the total cost.[59]

Fueling a vehicle with electricity versus gasoline will cut fuel costs by more than half. For the average American, at 11 cents per kilowatt hour (kWh), charging a purely electric vehicle would cost between three and five cents a mile.[60] This is the equivalent of $0.75 to $1.25 per gallon for a car that gets the equivalent of 25 miles per gallon (mpg). Compared with a conventional car getting 25 mpg at gas costs of $2.50 per gallon, the average electric car driver would save $600-$960 a year.[61] Combined with the $7,500 federal tax credit, these fuel savings over a 10-year period could lower the lifetime cost of an electric car as much as $17,000.

Fully electric cars will require far fewer repairs and maintenance over the lifetime of the car because there are far fewer moving parts. With an electric car, there are no oil changes, broken fan belts, or clogged filters. Since plug-in cars use regenerative braking, using the motor to slow the car and recharge the battery, brakes last much longer.[62] Lower maintenance costs could save plug-in car owners thousands of dollars over the lifetime of their cars, in addition to money saved on fuel.

Battery replacement would add significantly to the lifetime cost of a plug-in car, but advances in battery technology are reducing the need for replacement. Batteries being developed for plug-in cars today are expected to last five to eight years, or 100,000-200,000 miles, depending on the type of battery.[63] This means that some cars will need their battery replaced once over the car's lifetime, and others not at all. If prices come down as expected, this could be a few thousand dollars for a plug-in hybrid, or a few times that for a fully electric car.[64] Developers are also working to extend battery life, so that a battery could be expected to last the full lifetime of a car. Finally, the used batteries from plug-in vehicles—while no longer useful in vehicles—may retain some usefulness as a source of power storage for the electric grid, meaning that batteries may retain some value for consumers even when they must be replaced.

Manufacturers may also find new ways to improve the efficiency with which they manufacture electric vehicles. Wang Chuanfu, the founder of the Chinese battery company BYD, which has started manufacturing plug-in cars in China, has said that electric cars are to conventional cars as digital watches are to Swiss analog watches—they have fewer parts and require less fine tuning.[65] While established car companies are moving into plug-in hybrids before thinking seriously about fully electric cars, a number of new companies are bypassing gasoline engines altogether to take advantage of the simplicity of fully electric cars compared to plug-in hybrids.

New models for car ownership, like that proposed by Better Place, may also make it easier to buy an electric car. By paying for car batteries and electricity the way we pay for cell phones, with a monthly or per mile fee, any additional cost would be spread out over the lifetime of the car and there would be no risk of needing to pay for a replacement battery, removing the up-front barrier to buying an electric car. Centralizing the battery and electricity purchasing would also lower these costs for the supplier. A study by the University of California, Berkeley CET found that with this model, an electric car would cost less to fuel per mile than a gasoline car, including the cost of the battery and the cost of building fueling and battery changing stations—even if gas cost less than $4 a gallon. This assumes that a battery for an electric car with a 100 mile range costs $11,000 in 2012, the price predicted by leading battery manufacturer A123.[66]

Finally, there are several other factors that may narrow or eliminate the cost gap between conventional and plug-in vehicles. As mentioned earlier, plug-in hybrids could provide a valuable source of back-up or peak power for the electric grid. Fairly compensating the owners of plug-in hybrids, or battery leasers, for this service could mean additional savings of hundreds to thousands of dollars per year. Owners of plug-in hybrids would also enjoy additional savings in the event that gasoline prices spike. Moreover, federal incentives for plug-in hybrids can also reduce the cost differential.

Safety

Plug-in cars are just as safe as conventional cars, both in terms of the safety of the fuel and crash safety. Plug-in vehicles are no more likely than conventional vehicles to injure their occupants in a crash. The batteries used in plug-in cars have been shown to be safe, especially compared with the highly flammable gasoline used by conventional cars.

Plug-in cars will have to pass the same crash-safety tests as conventional cars, and with a new design it is likely that companies will install enough safety features to achieve the highest ratings.

Plug-in vehicles are just as safe as gasoline-powered vehicles, and possibly more so. Gasoline is highly flammable—in 2004, there were approximately 266,000 car fires in the United States, which resulted in the deaths of 520 people.[67] To improve upon this safety record, plug-in batteries will need to be safe in crashes and under a wide variety of circumstances.

Extensive testing of the batteries used today in plug-in cars has shown that they are safe. The nickel-hydride batteries used in hybrid cars have not had any safety problems in the 10 years they have been on the road.[68] Newer batteries—such as lithium-ion batteries—pose different challenges. Early lithium-ion batteries occasionally caught on fire when they were first used in laptops and cell phones.[69] However, the early safety problems with lithium-ion batteries have largely been addressed, and sound engineering and the addition of safety features can reduce the risks even further. Tesla Motors, whose all-electric Roadster uses the largest lithium-ion battery of any plug-in car sold today in the United States, has taken a number of precautions to ensure that the batteries are safe. Tesla tested its batteries for safety in hundreds of different situations, setting fire to batteries and crash-testing the cars, without safety failures.[70]

In short, plug-in vehicles must meet the same crash safety standards as conventional cars. And it is unlikely that reliance on batteries will pose dangers to drivers beyond those already posed by internal combustion vehicles.

Moving Toward a Plug-In Future

Changing the way our transportation system is powered isn't just a nice idea—it's an imperative. As oil and natural gas become harder to come by and the pressure to reduce global warming pollution grows, Americans will eventually have to find other ways to get around besides in internal combustion engine vehicles.

Plug-in cars are a promising alternative. We know how to build cars that run on electricity, we have a nationwide infrastructure capable of fueling them, and we know that they are environmentally preferable to the vehicles on the road today.

Getting to a future of a vehicle fleet that is free from dependence on oil and produces dramatically lower emissions of global warming pollution, however, won't happen overnight and it won't be easy.

The initial hurdle will be to demonstrate the viability of plug-in vehicles under real-world conditions. Next will come the challenge of expanding plug-in vehicle ownership to more Americans. Finally, the nation will need to take steps to reap the full environmental and economic benefits of plug-in hybrids through improvements to the electric grid.

Governments have an important role to play in making all of these simultaneous processes happen. With a thoughtful strategy and a strong public policy commitment, plug-in vehicles could come to play a meaningful role in addressing the nation's environmental and energy challenges—and do so in the foreseeable future.

Getting Plug-Ins on the Road

Several car companies have plans to produce plug-in cars within the next couple of years. Those vehicles, however, are likely to be relatively expensive vehicles targeted to "early adopters"—the same technologically savvy consumers who purchased the first personal computers, cellular telephones, solar panels or conventional hybrid-electric cars.

There are a number of steps that governments can take to get plug-in vehicles on the road, and to help make the jump from niche market to mass market.

Encourage Research and Development

States and the federal government should encourage research and development for plug-in cars, while making sure that these incentives are tied to achieving the goal of getting plug-in cars on the road.

Recent years have seen tremendous improvement in battery technology, but further research on advanced batteries is needed. The American Recovery and Reinvestment Bill included $2 billion in funding for advanced battery research for plug-in vehicles, and $400 million to encourage electric vehicle development.[71] This funding will accelerate improvements in plug-in technology, but there are still other areas of battery research that are underfunded, such as more basic battery research on new battery materials.[72] States and the federal government should continue to support battery and other plug-in vehicle technology development. At the same time, any direct government subsidies to the automobile industry should be tied to the achievement of specific benchmarks to ensure that funding is used to bring environmentally preferable vehicles to consumers.

Provide Incentives for the Purchase of Plug-In Cars

In the early years, plug-in vehicles will be much more expensive than conventional vehicles. Financial incentives for the purchase of plug-in vehicles can help get plug-ins on the road and encourage manufacturers to invest in mass producing plug-in vehicles, thereby reducing their costs.

There is currently a federal tax credit for plug-in vehicles of $2,500-$7,500, depending on the distance a car can be driven on electric power. There is also a tax credit for 10 percent of the cost of converting a car to a plug-in electric vehicle, up to $4,000. Some states have additional incentives for buying plug-in cars.[73]

These incentives likely will not be sufficient to close the gap in up-front costs between plug-in and conventional vehicles—at least in the near term. But they should provide a shot in the arm to encourage early adopters to pursue plug-ins. Even more important than the size of the incentives, however, is their duration—federal and state governments should develop and implement long-term incentive structures to send a message to manufacturers and the public that their commitment to plug-in vehicles is real.

Use Plug-In Vehicles in Fleets

Vehicle fleets, such as those used by governments or delivery companies, are particularly suited to use plug-ins. Fleet vehicles are often used on a defined schedule and within a defined area, meaning that range isn't as much of an issue. Fleet vehicles are often refueled centrally, meaning that they do not need to rely on the availability of public charging infrastructure. Finally, fleet owners may be more willing to sustain higher upfront cost for vehicles with the promise of longer-term savings.

Managers of government fleets should be some of the first purchasers of plug-in cars. The federal and state governments, as well as many cities, own fleets of vehicles that employees use for official purposes. Integrating plug-in cars into these fleets will encourage more widespread use of plug-in cars by enlarging the market and demonstrating to consumers that plug-in cars work. They will also lower the fleets' environmental impact.

A number of states and cities have laws to lower the global warming impact of their fleets. Some examples include:

- Massachusetts has a law that requires 50 percent of state vehicles to be hybrids by 2018.[74]

- Oregon, as part of its plan to reduce global warming emissions in the state to 75 percent below 1990 levels by 2050, requires state agencies to establish annual global warming emission reduction targets for themselves, including emissions from their vehicle fleets.[75]

- Seattle has already converted a dozen of the Toyota Priuses in its fleet to plug-in hybrids.[76]

In addition, the American Recovery and Reinvestment Act included $300 million in funding to replace older vehicles owned by the U.S. government with plug-in and alternative fuel cars.[77]

By using more plug-in cars, cities and states reduce their global warming impact and other pollution, but the benefits of these policies extend beyond direct emissions reductions. Governments that buy low emissions cars enlarge the early market for these cars, which encourages companies to develop plug-ins. They bring plug-ins closer to mass production, lowering the cost for everyone. And, governments with plug-in cars in their fleets have an incentive to install chargers around the areas where the cars will be used, which in turn will encourage more residents in those areas to buy plug-in cars, knowing that chargers are available.

States and the federal government should also provide incentives for private fleet owners to purchase plug-in vehicles. Private fleet owners are more likely than the average consumer to make decisions about a car purchase based on its lifetime cost, so the same incentive for fleet owners will result in more car purchases.

Set Ambitious Targets for Technology Development

Once the viability of plug-in vehicles has been demonstrated, the nation will face the challenge of scaling up plug-ins to the mass market. One way to help make that leap is to enact policies that require automakers to introduce increasing numbers of plug-in vehicles over time.

California, for example, pushed vehicle technology forward with its Zero-Emission Vehicle program, which ultimately led to the creation of fully electric cars that made today's hybrid cars possible. The program is currently designed to promote the development and sale of a wide variety of clean vehicles—including plug-in vehicles. Other states could adopt the California program and the federal government could establish similar requirements, thereby pushing automakers to offer more plug-in hybrids for sale to consumers.

Reaping the Full Benefits of Plug-In Cars

Getting large numbers of efficient plug-in cars on the road is important, but is only half the battle. To take full advantage of the benefits of plug-in cars, America must also move to clean up the nation's electricity grid, expand access to recharging infrastructure, and tap the potential of plug-ins to contribute to the stability of the electric grid.

Enact a Low-Carbon Fuel Standard

The larger goal of using electricity as a fuel is to lower U.S. global warming emissions from transportation. A low-carbon fuel standard is a policy tool to advance this goal directly. It values each vehicle fuel based on its lifecycle global warming emissions. By incorporating the value of low emissions into fuel cost, a low-carbon fuel standard will increase the use of clean fuels while also preventing an increase in dirtier alternatives, such as coal to liquid, shale oil, and oil from tar sands.

A low-carbon fuel standard could be implemented in several ways, but one of the easiest routes would be to require that fuel providers—those who refine, import, or blend fuel—sell fuel with a declining carbon content, or buy credits from electric utilities that supply electricity to plug-in cars. A beginning point could be a requirement that transportation fuels be 10 percent less carbon-intensive by 2020, the standard set by the state of California.

Fuel providers would be required to report the full life-cycle global warming pollution of the fuels that they sell.[78] Life-cycle analysis of global warming emissions should include emissions from farming practices, land use changes here and worldwide, refining, shipping, and use of the fuel. The efficiency for vehicles using non-petroleum fuels in high-efficiency plug-in vehicles should also be factored in. All global warming pollutants, including carbon dioxide, methane and nitrogen dioxide, from all stages of fuel production (including secondary land use impacts) should be considered.

A low-carbon fuel standard would affect plug-in cars in two ways. First, utilities may encourage the purchase of plug-in hybrids so that they could reap the value of the credits refiners need to obtain to comply with the standard. Second, because the value of the credits would be tied to the full life-cycle emissions of the fuel, the standard would provide a small but meaningful incentive to clean up the electric grid.

A 10 percent reduction in global warming emissions from transportation fuels by 2020 is an ambitious, but reasonable, target. By starting the low-carbon fuel standard with a fairly low requirement and increasing the target each year, farmers, researchers and investors can anticipate future demand, developing new energy sources and technologies.

To avoid negative consequences from increasing production of low-carbon fuels, any low-carbon fuel standard should include provisions to protect air quality, public health, and the environment.

Expand the Use of Clean, Renewable Energy

A clean electricity grid is vital to unlocking the potential large-scale environmental benefit of plug-in vehicles.

Requiring that electric utilities increase the percentage of power that they supply from renewable sources of electricity would ensure that electricity in the United States becomes cleaner over time. Many states have renewable energy standards which set specific benchmarks for the use of clean electricity. The federal government should set a national renewable energy standard, with a minimum of 25 percent of our energy supplied by clean and renewable sources such as wind and solar power by 2025.

States and the federal government should make it easier for homeowners and businesses to install on-site renewable power such as solar panels and wind turbines. Plug-in cars can also be used to store extra electricity generated by on-site wind and solar power—for example, a company could install an array of solar panels on its garage, which could charge employees' cars during the day. The federal government and many states have incentives and other laws that encourage residential and commercial on-site renewables. These policies, such as requirements that new houses are wired to allow for solar panel installation, should be in place in every state.

Develop Infrastructure

Governments can further encourage the use of plug-in cars by encouraging the development of charging and grid infrastructure that will allow drivers to take full advantage of plug-in cars.

Implementing a "smart" grid will allow better communication and control of electricity use for both consumers and utilities. This will make it possible to manage increasing numbers of plug-in cars and use more diverse and distributed sources of clean energy. A "smart" grid will also allow utilities to take advantage of the battery storage available in plug-in cars, and make the grid more reliable and efficient.[79] The American Recovery and Reinvestment Act included $11 billion in funding to develop a smart grid. The federal government, states, and utilities should continue to move forward on modernizing our electrical grid so that we can manage and take advantage of an increasing amount of clean energy and plug-in cars.

Governments can also help expand access to recharging infrastructure—particularly for would-be plug-in drivers who do not have a home garage. Local governments should install chargers and encourage businesses to do so as well. Local governments could make spots on the sidewalk or in public parking lots available to businesses that want to install for-profit chargers, and local governments could also install public chargers on publicly owned property.

States and the federal government should build or encourage charging infrastructure to make it possible for drivers to use electric cars as their primary vehicles. Installing fast chargers or battery swapping stations along highways would encourage more people to buy fully electric cars. For example, states could install fast chargers at highway rest stops. There is already a federal incentive for businesses of 50 percent of the cost of installing a car charger, up to $50,000, which gas station owners could use to install fast chargers. The credit expires at the end of 2010, and should be extended so that it will be in effect when plug-in cars are more widely used.[80]

Cap Carbon Emissions

Another way to reduce the global warming emissions produced by plug-in vehicles is to enact a mandatory, economy-wide cap on global warming emissions. While the most immediate impact of an emission cap would be on the electric grid, encouraging the replacement of polluting power plants with cleaner ones, a strong cap could eventually also help to encourage the sale of plug-in vehicles.

The cap should be set at levels consistent with what science tells us is necessary to prevent the worst impacts of global warming. At minimum, total U.S. emissions should be reduced by 35 percent below 2005 levels by 2020 and by 80 percent below 2005 levels by 2050. The transportation sector is responsible for a third of the global warming pollution in the United States, so in order to achieve this level of reduction we will need to significantly reduce global warming emissions from transportation.[81]

To use our resources most effectively, any emission trading program used to comply with a global warming emission cap should auction, rather than give away, emission allowances and use the proceeds of that auction to accelerate the transition to a clean energy economy and reduce the cost of the program to consumers. Plug-in vehicles and recharging stations might be among the critical clean energy technologies that could receive funding through auction revenues.

Notes

1 Thomas A. Becker, Center for Entrepreneurship & Technology, University of California, Berkeley, *Electric Vehicles in the United States: A New Model With Forecasts to 2030*, July 14, 2009.

2 U.S. Department of Transportation, Bureau of Transportation Statistics, *National Household Travel Survey*, 2003.

3 K. Parks, P. Denholm, and T. Markel, National Renewable Energy Laboratory, *Costs and Emissions Associated With Plug-In Hybrid Electric Vehicle Charging in the Xcel Energy Colorado Service Territory*, May 2007.

4 Scott McCredie, "Plug-In Hybrids: More Hype Than Hope?" *Wired*, 6 May 2009.

5 Google.org, *RechargeIT Driving Experiment*, downloaded from www.google.org/recharge/experiment/, 22 May 2009.

6 "Timeline: Life & Death of the Electric Car," *NOW on PBS*, 9 June 2006.

7 Mark Clayton, "Worldwide Race to Make Better Batteries," *The Christian Science Monitor*, 22 January 2009.

8 RAV4-EV: Seattle Electric Vehicle Association, *Toyota RAV4 EV*, downloaded from www.seattleeva.org/wiki/Toyota_RAV4_EV, 15 May 2009; 2002 RAV4: ConsumerGuide Automotive, *2002 Toyota RAV4: Overview*, downloaded from consumerguideauto.howstuffworks.com/2002-toyota-rav4.htm, 15 May 2009.

9 Energy-Climate Committee, Sierra Club California, *Plug for Plug-Ins*, 29 July 2006.

10 Ibid.

11 Sherry Boschert, *The Cleanest Cars: Well-to-Wheels Emissions Comparisons*, May 2008.

12 See note 9.

13 See note 11.

14 Michael Kintner-Meyer, Kevin Schneider, and Robert Pratt, Pacific Northwest National Laboratory, *Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional Power Grids, Part 1: Technical Analysis*, 2007.

15 Ibid.

16 See note 1.

17 Ibid.

18 W. Short and P. Denholm, National Renewable Energy Laboratory, *A Preliminary Assessment of Plug-In Hybrid Electric Vehicles on Wind Energy Markets*, April 2006.

19 See note 14.

20 Electric Power Research Institute and Natural Resources Defense Council, *Environmental Assessment of Plug-In Hybrid Electric Vehicles: Volume 2: United States Air Quality Analysis Based on AEO-2006 Assumptions for 2030*, July 2007.

21 Ibid.

22 Energy Information Administration, U.S.

Department of Energy, *Annual Energy Outlook 2007 with Projections to 2030*, February 2007.

23 See note 14.

24 73 percent of the U.S. fleet could be powered with electricity from existing capacity on the U.S. grid, and the U.S. light vehicle fleet uses 97 percent of the gasoline in the U.S.: See note 14; 2008 petroleum consumption: Energy Information Administration, U.S. Department of Energy, *Annual Energy Review 2008*, 26 June 2009.

25 See note 14.

26 Pacific Northwest National Laboratory, *Smart Charger Controller Simplifies Electric Vehicle Recharging* (press release), 30 April 2009.

27 Tammy Thompson, Michael Webber and David T Allen, *Air Quality Impacts of Using Overnight Electricity Generation to Charge Plug-In Hybrid Electric Vehicles for Daytime Use*, 13 January 2009.

28 Peter Lilienthal and Howard Brown, National Renewable Energy Laboratory, "Potential Carbon Emissions Reductions from Plug-In Hybrid Electric Vehicles by 2030," in Charles F. Kutscher, Ed., American Solar Energy Society, *Tackling Climate Change in the U.S.: Potential Carbon Reductions from Energy Efficiency and Renewable Energy by 2030*, January 2007.

29 Austan Librach, Austin Energy, personal communication, 24 June 2009.

30 Steven Letendre, Paul Denholm, and Peter Lilienthal, "Electric & Hybrid Cars: New Load, or New Resource?" *Public Utilities Fortnightly*, December 2006.

31 Ibid.

32 Ibid.

33 Willett Kempton, Jasna Tomić, "Vehicle-to-Grid Power Implementation: From Stabilizing the Grid to Supporting Large-Scale Renewable Energy," *Journal of Power Sources*, 1 June 2005.

34 "V2G Generates Electricity—And Cash," *University of Delaware Messanger*, 2008.

35 Steven Letendre, Paul Denholm, and Peter Lilienthal, "Electric & Hybrid Cars: New Load, or New Resource?" *Public Utilities Fortnightly*, December 2006.

36 See note 33.

37 Ibid.

38 See note 18.

39 See note 29.

40 Carolyne Zinko, "Electric Car's Acceleration Leaves Owner Charged Up," *San Francisco Chronicle*, 1 May 2009.

41 Jack Ewing, "Test-Driving the Electric Mini," *BusinessWeek*, 12 March 2009.

42 U.S. Department of Energy, Vehicle Technology Program, *How Do Gasoline and Electric Vehicles Compare?*, 7 November 2005.

43 Kevin Bullis, "GM's Plug-In Hybrid," *Technology Review*, 5 December 2006.

44 Rick Cotta, "Hybrid Batteries: None the Worse for Wear?" *How Stuff Works*, downloaded from consumerguideauto.howstuffworks.com/hybrid-batteries-none-the-worse-for-wear-cga.htm#, 25 May 2009.

45 Chris Vander Doelen, "Auto Industry in Throes of Momentous Shift," *Canada.com*, 19 May 2009.

46 A123Systems' Prius conversion charges in 5.5 hours: A123Systems, *Hymotion L5 Plug-In Conversion Module (PCM) Owner's Manual*, 2008; BYD's plug-in hybrid with a 60 mile range charges in nine hours: Anthony Kuhn, "Chinese Electric Car Jolts the Competition," *NPR*, 13 January 2009; Chevy Volt will charge in eight hours: David Pierce, Brent Snavely and Katie Merx, "Inside the Volt," *Detroit Free Press*, 17 September 2008.

47 U.S. Department of Energy, Energy Information Administration, *Square Footage Measurements and Comparisons:* Caveat Emptor*: 2001 Residential Energy Consumption Survey*, 22 May 2003.

48 See note 2.

49 Ron Cogan, "Hyundai Santa Fe EV," *Green Car*, 1 October 2007.

50 Hawaii: See note 49; Washington, D.C.: District of Columbia Department of Transportation, *Mayor Fenty Announces Partnership With Nissan North America and AeroVironment* (press release), 7 May 2009.

51 "Electric Evangelist," *The Economist*, 30 April 2009.

52 See note 1.

53 See note 51.

54 Conversion cost: A123Systems, *Hymotion*, downloaded from www.a123systems.com/hymotion, 14 May 2009; tax incentive: U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, *Hybrid Electric Vehicle Incentives and Laws*, 3 February 2009.

55 Bill Vlasic and Nick Bunkley, "G.M. Puts Electric Car's City Mileage in Triple Digits," *New York Times*, 11 August, 2009.

56 A. Simpson, National Renewable Energy Laboratory, *Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology*, November 2006.

57 Ibid.

58 See note 1.

59 American Automobile Association, *Your Driving Costs*, 2009. Note: this estimate assumes an average of 15,000 miles driven per year.

60 Kilowatt hour per mile: U.S. Department of Energy, Energy Efficient and Renewable Energy, *What is an Electric Vehicle?*, 3 January 2009; Cost of electricity by state: Energy Information Administration, *Average Re tail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Year-to-Date through January 2009 and 2008*, 22 April 2009.

61 This assumes an average of 12,000 miles driven per year.

62 Plug In America, *Frequently Asked Questions*, downloaded from www.pluginamerica.org/learn-about-plug-ins/frequently-asked-questions.html, 15 May 2009.

63 Chevrolet Volt 5-8 years: Mark Clayton, "Worldwide Race to Make Better Batteries," *The Christian Science Monitor*, 22 January 2009; Tesla Roadster over five years: Martin Eberhard CEO and JB Straubel CTO, Tesla Motors, *A Bit About Batteries* (blog post), 30 November 2006; Nickel Metal Hydride batteries 150,000-200,000 miles: Plug In America, *Frequently Asked Questions*, downloaded from www.pluginamerica.org/learn-about-plug-ins/frequently-asked-questions.html, 15 May 2009.

64 Fritz R. Kalhammer, Bruce M. Kopf, David H. Swan, et al, prepared for State of California Air Resources Board, *Status and Prospects for Zero Emissions Vehicle Technology: Report of the ARB Independent Expert Panel 2007*, 13 April 2007; Mark Clayton, "Worldwide Race to Make Better Batteries," *The Christian Science Monitor*, 22 January 2009.

65 Norihiko Shirouzu, "Technology Levels Playing Field in Race to Market Electric Car," *Wall Street Journal*, 12 January 2009.

66 See note 1.

67 "New Warning to be Issued About Deadly Car Fires," *ABC News*, 12 October 2005.

68 See note 44.

69 Isidor Buchmann, *Lithium-ion Safety Concerns*, BatteryUniversity.com, February 2007.

70 Tesla Motors, *Safety*, downloaded from ww.teslamotors.com/design/safety.php, 19 May 2009.

71 Committee on Appropriations, U.S. House of Representatives, *Summary: American Recovery and Reinvestment Conference Agreement* (press release), 13 February 2009.

72 Brian Clark Howard, "What's Next, Electric Cars with Dirt-Based Batteries or Ethanol?" *The Daily Green*, 2 May 2009.

73 U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, *Hybrid Electric Vehicle Incentives and Laws*, 3 February 2009.

74 U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, *Massachusetts Hybrid Electric Vehicle Laws and Incentives*, 3 February 2009.

75 U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, *Oregon Hybrid Electric Vehicle Laws and Incentives*, 3 February 2009.

76 See note 4.

77 Committee on Appropriations, U.S. House of Representatives, *Summary: American Recovery and Reinvestment Conference Agreement* (press release), 13 February 2009.

78 Many of the recommendations in this section are based on Alexander Farrell (UC Berkeley) and Daniel Sperling (UC Davis), *A Low-Carbon Fuel Standard for California, Part 2: Policy Analysis*, 1 August 2007.

79 Martin LaMonica, "Will Anyone Pay for the 'Smart' Power Grid?" *CNET News*, 16 May 2007.

80 U.S. Department of Energy, Alternative Fuels & Advanced Vehicles Data Center, *United States (Federal) Incentives and Laws: Alternative Fuel Infrastructure Tax Credit*, 3 February 2009.

81 Energy Information Administration, *Emissions of Greenhouse Gases Report*, 3 December 2008.