Charging Forward

The Emergence of Electric Vehicles and Their Role in Reducing Oil Consumption

ENVIRONMENT MARYLAND
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Executive Summary

America's reliance on gasoline-powered vehicles has long contributed to air pollution, including global warming emissions, and our nation's dependence on oil. In the past decade, however, the automobile market has begun to change, integrating new technologies that are dramatically less dependent on gasoline. Hybrid electric vehicles, powered in part by energy stored in a battery, have become increasingly popular.

Now, fully electric vehicles, with zero direct emissions, are emerging as a market-viable alternative to gasoline-powered vehicles. For the first time in the history of the modern automobile industry, vehicles that do not run on oil have started to appear on American roads, signaling the beginning of the end for the monopoly of the internal combustion engine.

Electric vehicles have arrived and will provide extensive environmental benefits. Increasing the number of electric vehicles on the road will yield even greater cuts in pollution and oil use.

More than 30,000 electric vehicles are already on the road in the United States, and more are coming soon. Dealers sold 17,000 electric vehicles in the first year that they were on the market, far exceeding the 9,300 hybrids sold the first full year those vehicles were available, and nearly matching the 20,000 hybrids sold in the first two years hybrids were on the market. In 2012, sales of electric vehicles through May are on pace to show tremendous growth over 2011.

- The **Chevrolet Volt**, a plug-in hybrid electric vehicle, is the top-selling electric vehicle model in the United States to date, with more than 15,000 units sold.
- The **Nissan Leaf**, an electric vehicle, is the second highest seller with more than 12,000 sold.
- Additional models, including the Ford Focus EV and the Toyota Prius Plug-in Hybrid, covering a wide range of car sizes and styles, have entered the market in 2012.

The Center for Automotive Research (CAR) projects that 469,000 electric vehicles could be sold between 2012 and 2015. Meeting CAR's sales projections could lead to benefits including:

- Preventing the emission of **629,000 metric tons of global warming pollution annually,** even with much of the electricity for vehicles being generated at coal- and natural gas-fired power plants. That's equal to removing 123,000 conventional passenger vehicles from the road. Powering the vehicles with renewable energy would raise the potential reduction in global warming pollution to 1.96 million metric tons, equal to the emissions from 385,000 conventional passenger vehicles.

- Reducing oil consumption by **2.6 million barrels of oil—**the equivalent of removing 221,000 2012 model gasoline vehicles from the road altogether.

More ambitious schedules for electric vehicle deployment are possible. Putting 1 million electric vehicles on the road by 2015, as has been proposed by President Obama and others, would offer even greater pollution and oil savings benefits, reducing oil consumption by over 5.6 million barrels annually.

Electric vehicle support infrastructure is spreading rapidly through the country: as of March 2012, more than 7,000 charging stations have been installed, and more are on their way. Though most recharging of electric vehicles will happen when owners are at home, public charging stations offer drivers of electric vehicles greater flexibility. Federal grants and partnerships with private companies are helping cities pave the way for large-scale use of electric cars. Leading states have developed large numbers of charging stations, preparing them for rapid rollout of electric vehicles. (See Table ES-1.)

Electric vehicles are ready to begin a wholesale transformation of the automobile market, reducing pollution and oil dependence from personal transportation.

Table ES-1: Top Ten States for Public Electric Car Charging Stations, as of March 2012

State	Number of Charging Stations Installed
California	1,718
Washington	674
Texas	570
Michigan	480
Florida	475
Oregon	415
New York	367
Maryland	262
Illinois	245
North Carolina	211

Public policy can help speed the day in which cars are powered by clean electricity instead of dirty oil. In order to bring this about, policymakers should:

- **Incentivize owning and driving electric vehicles** both with tax credits and other financial incentives.

- **Encourage construction of charging stations** to allow drivers the option of recharging vehicles at work or during longer trips away from home.

- **Invest in research** to continue reducing the cost and improving the performance of electric vehicles.

Additionally, policymakers should make sure that the value of electric vehicles is maximized by:

- **Promoting renewable energy**, so that the electricity used to charge electric vehicle batteries is produced as cleanly as possible.

- **Developing a smart grid** to allow vehicle batteries to function as storage for the larger electricity system.

Introduction

Paying for gas—and dealing with the pollution it causes—has been an almost inescapable element of most Americans' lives for decades. From the neighborhoods we live and work in to the extensive highway system we travel on, much of our nation's infrastructure is built for personal cars, and personal cars have been almost universally gasoline-burning, spewing air pollution with every trip.

That is starting to change.

In the past year and a half, for the first time in modern history, a significant number of vehicles capable of operating without petroleum fuel have been sold in the United States. From the fully-electric Nissan Leaf to the plug-in hybrid Chevy Volt, the new vehicles share a crucial feature: they can be powered entirely with electricity.

Replacing gasoline with electricity as the fuel of choice for personal transportation would mean more than just replacing trips to the gas station with plugging into an outlet. It would mean replacing oil—which is getting increasingly dirty and dangerous—with electricity, which we know how to produce cleanly. It would mean replacing largely imported oil, a major net drain on the American economy, with homegrown electric power.

The electric cars hitting the road today don't look much different than ordinary cars. For the air we all breathe, though, the difference between a gasoline car and a vehicle without a gas tank or a tailpipe can be like the difference between night and day. Electric vehicles are a key part of our nation's efforts to end our reliance on oil and build a cleaner future.

Pollution from Automobiles Harms America's Environment, Economy and Health

For decades—at least since the oil shocks of the 1970s raised awareness of America's dependence on imported oil—policymakers have talked about reducing oil dependence. While efforts towards that goal have achieved some success at times—temporarily reversing the growth of oil consumption in the early 1980s—increases during the 1990s and 2000s raised U.S. oil consumption to all-time highs immediately before the late 2000s recession.[1]

Oil dependence has significant consequences for the United States. Oil imports draw a huge amount of money out of the economy every year—$327 billion in 2011 alone.[2] Higher gas prices also mean families spend more of their household budgets on gasoline. Most Americans have little choice but to pay more when gasoline prices rise because oil has become so central to our way of life.[3]

Internal combustion engine-driven automobiles release a number of pollutants into the atmosphere. These range from pollutants with short-term effects—such as contributors to smog—to pollutants like carbon dioxide that contribute to longer-term environmental degradation. Conventional automobiles contribute to several of the major pollution and public health problems our society faces.

Automobile Pollution Contributes to Smog

Smog is the common term for ground-level ozone, a form of pollution that can threaten respiratory health.

Ground-level ozone is generally not emitted directly, but instead forms from a reaction between chemicals in the atmosphere. When nitrogen oxides and hydrocarbons come together in the presence of sunlight, ozone is formed.[4] Both nitrogen oxides and hydrocarbons (essentially, incompletely combusted fuel molecules) are part of motor vehicle emissions.

Smog poses both short and long-term threats to human health. Short-term exposure to ozone can cause lung irritation and inflammation, coughing, and aggravation of lung problems like asthma. Over the longer term, exposure to ozone can increase susceptibility to various lung diseases, such as bronchitis, and cause permanent damage to lung tissue.[5]

Increased emphasis on limiting emissions of ozone-forming chemicals from automobiles and other sources has paid off in the form of a decline in average ozone levels over the past several decades.[6] Despite that improvement, ozone remains a serious public health concern. According to the American Lung Association, 38 percent of Americans live in counties where ozone reaches levels high enough to damage public health.[7]

The chemicals that react to form ozone, meanwhile, can pose health risks in their own right. Some of the hydrocarbons found in automobile exhaust are carcinogenic. [8] Nitrogen oxides, meanwhile, can cause lung inflammation in the population at large, and increased symptoms in people with asthma.[9]

Automobile Pollution Contributes to Global Warming

Automobile engines emit carbon dioxide, the leading cause of global warming. Carbon dioxide in the atmosphere causes more of the heat from the sun to be trapped in the atmosphere and less to radiate back into space, increasing the temperature of the Earth over time.

The effects of global warming have been increasingly evident over the past decade. Among them:

- Nine of the ten warmest years on record have occurred since 2000. The warmest year on record occurred in 2010; 2011 was the ninth warmest.[10]
- Severe weather events have occurred with increasing frequency in recent years. For example, a 2007 Environment America Research & Policy Center report found that the frequency of extreme precipitation events increased by 24 percent across the contiguous United States between 1948 and 2006.[11]
- Arctic sea ice has steadily retreated as temperatures have warmed. Sea ice reached its minimum extent in 2007. In 2011, sea ice reached its second-lowest recorded extent, declining to its smallest extent on September 9.[12]

If global warming is allowed to continue unchecked, severe consequences are likely to result.

- Global warming will lead to more heat waves, threatening vulnerable populations across the United States and the productivity of agriculture.[13]
- Rising temperatures will lead to rising sea levels, as ice caps on Greenland and Antarctica melt and sea water expands in volume at higher temperatures. Recent research suggests that sea levels are likely to increase by between 30 and 75 inches by 2100.[14]
- Higher temperatures are already changing the pattern of the seasons, and leading to habitat loss and migration as species react to changing weather patterns.[15]

Automobiles are a significant source of global warming pollution in the United States. In 2008, motor gasoline used for transportation accounted for 18 percent of all U.S. emissions of global warming pollution (this figure includes emissions from some automobiles that are not personal cars, but excludes emissions from diesel-powered vehicles).[16]

Oil Is Getting Dirtier and Electricity Is Getting Cleaner

In April 2010, the Deepwater Horizon oil drilling rig exploded in the Gulf of Mexico, beginning an environmental disaster that dumped more than 200 million gallons of oil into the Gulf. We are only beginning to fully understand the impact that this catastrophe is having on the ecology of the Gulf, and the lives and health of people in the region. But the Deepwater Horizon disaster is more than an isolated incident. Rather, it is the most dramatic demonstration of the increasing risks that oil companies are taking to satisfy the increasing global thirst for oil.

The danger of deepwater drilling is that a single accident can dump massive amounts of oil into the ocean. Other unconventional sources of oil have their own environmental problems. The production of oil from Canada's tar sands in Alberta is one of the most ecologically damaging industries ever constructed. It destroys vast tracts of wilderness and causes water and air pollution, with tar sands-based oil releasing 14 to 25 percent more global warming pollution than conventional oil.[17] The U.S. Energy Information Administration (EIA) projects that production of tar sands oil will triple over the next 25 years from 1.5 million barrels per day to 4.8 million barrels per day.[18] Production of oil out of shale rock formations in the western United States has similarly devastating impacts on air and water quality, as well as global warming.

While our future oil supplies are getting dirtier, our sources of electricity have the potential to get cleaner. Twenty-nine states plus the District of Columbia currently have some version of a Renewable Electricity Standard requiring that utilities generate an increasing percentage of electricity from renewable energy sources.[19] The EIA currently projects that renewable sources of energy will grow from 10 percent of all electricity generation to 16 percent by 2035.[20] With the right policies in place, we can achieve much greater increases in generation of renewable electricity, further strengthening the environmental benefits of electric vehicles.

Electric Vehicles Can Help Cut Oil Dependence and Air Pollution

Basics of Electric Vehicles

Electric cars come in several variations, but share one crucial feature: they use electricity as a fuel, reducing or eliminating their need for gasoline.

Partially electric drive trains began to make an impact on the American automobile market in the early 2000s with the introduction of **hybrid electric vehicles (HEVs)**, like the Ford Escape hybrid and Toyota Prius. American drivers purchased more than 2 million of these vehicles between 1999 and the end of 2011.[21] These cars have batteries and an electric motor that provide assistance to the gasoline engine.

HEVs have a number of features that make them more fuel-efficient than conventional cars. For instance, a regenerative braking system allows the car's electric motor to capture and store the energy of the car's momentum while slowing down, eliminating a major source of waste. This feature, combined with the ability to shut down the internal combustion engine when the car is moving very slowly or is stopped, makes these cars much more efficient than conventional cars for stop-and-start driving in city traffic.

The difference between hybrids and the electric vehicles described in this report is that HEVs need to operate their internal combustion engine in order to drive more than a brief distance. By contrast, the two categories of vehicles discussed in this report can complete a full trip on electric power alone. For a driver, that means that shorter trips—commutes to and from work, for example, or weekend errands—can be accomplished without engaging the gasoline engine.

Plug-in hybrid electric vehicles (PHEVs), contain both an electric motor and an internal combustion engine. PHEVs can be plugged into an external power source to charge their batteries, which allows them to run entirely on battery power within a given range. Beyond that distance, they engage their internal combustion engine, either to operate a generator that powers the electric motor or to power the vehicle directly. Even in regions with relatively dirty power plants generating electricity, PHEVs have lower emissions than do typical vehicles powered solely by gasoline. The Chevy Volt is presently the top-selling PHEV in the United States, having sold 7,671 units in 2011.[22]

The second category of electric vehicles are **battery electric vehicles (BEVs)**, which have no internal combustion engine. These vehicles operate entirely on battery power, and can only take trips within the range of their battery charge before stopping to recharge. They produce no direct emissions because they don't consume any fossil fuels on-board the vehicle, and are cleaner than average gasoline- or diesel-powered cars.

Electric Vehicles Can Reduce Fossil Fuel Dependence and Cut Pollution

Electric vehicles consume less fossil fuel and produce less carbon dioxide and health-threatening pollutants than conventional vehicles, even when the electricity that powers the electric vehicles comes mainly from coal-fired power plants.

Reduced Oil Consumption

A January 2011 study by the Center for Automotive Research (CAR) projects that

Table 1: Annual Oil Savings if 469,000 Electric Vehicles Are Sold by 2015[26]

State	Barrels of Oil Saved	State	Barrels of Oil Saved
AK	4,960	MT	7,555
AL	18,620	NC	65,959
AR	15,701	ND	2,959
AZ	70,575	NE	9,671
CA	637,722	NH	17,179
CO	56,125	NJ	73,639
CT	45,769	NM	19,336
DC	8,197	NV	21,687
DE	7,803	NY	141,870
FL	139,287	OH	63,509
GA	45,411	OK	17,049
HI	12,387	OR	55,501
IA	21,859	PA	88,786
ID	10,690	RI	10,067
IL	98,491	SC	23,127
IN	36,692	SD	4,637
KS	19,680	TN	27,783
KY	17,459	TX	145,806
LA	14,655	UT	17,094
MA	81,284	VA	95,092
MD	65,491	VT	9,449
ME	12,927	WA	94,640
MI	46,422	WI	42,226
MN	38,992	WV	7,992
MO	33,721	WY	3,689
MS	7,523	**U.S. Total**	**2,634,747**

469,000 electric vehicles could be sold in the United States between 2012 and 2015. Combined with the 17,000 electric vehicles sold in 2011, that would mean a total of 486,000 electric vehicles on the road by the end of that year.[23] (For reference, there were approximately 234 million passenger cars on the road in 2009.[24])

Putting this many electric vehicles on the road would reduce U.S. oil consumption significantly. The electric vehicles that CAR projects will be sold between 2012 and 2015 would lead to a 2.6 million barrel reduction in the nation's oil consumption annually, the equivalent of removing 221,000 model year 2012 vehicles from the road altogether.[25] A faster EV rollout would lead to greater savings; putting 1 million EVs on the road by the end of 2015 would create annual oil savings of 5.6 million barrels per year, or as much as is consumed by 471,000 model year 2012 vehicles.

Reduced Pollution

Electric vehicles will also have a significant impact on emissions of pollutants that threaten public health and that contribute to global warming. Compared to a conventional vehicle fleet, a fleet incorporating a significant number of plug-in hybrids and electric vehicles will emit less nitrogen oxides and carbon dioxide.

Increasing the use of electric and plug-in hybrid electric vehicles can reduce emissions of hydrocarbons, nitrogen oxides, and sulfur dioxide. According to a study by the Natural Resources Defense Council and the Electric Power Research Institute, the use of plug-in hybrid-electric vehicles would improve air quality for most regions in 2030.[27] That study was based on a 2006 forecast of future electricity generation that included many new coal-fired power plants. Since 2006, the projected number of new coal-fired power plants has dropped, meaning that future electricity generation could be less polluting and electric vehicles could produce greater improvements in air quality.

Electric vehicles also reduce global warming pollution. By using energy more efficiently and by relying on electricity, which produces less global warming pollution than gasoline, electric vehicles emit less global warming pollution than do conventional cars. The scale of the savings depends on the mix of coal, natural gas and renewable energy used to produce electricity where the vehicle is charged. This ratio varies from one region of the country to another.

- In California, which has a relatively clean electricity mix, an electric vehicle would produce 66 percent less global warming pollution per mile than a comparably sized gasoline-powered vehicle.[28]

- An electric vehicle in Texas, where the electric grid is not as clean as in California, would release 41 percent less global warming pollution.

- Even in Michigan, which has one of the most coal-dependent and polluting electricity mixes in the nation, an electric vehicle would produce 29 percent less global warming pollution than an average new gasoline-powered vehicle.

The cumulative savings would be significant. If electric vehicle sales match CAR's projections, the 469,000 electric vehicles sold between 2012 and 2015 would prevent 629,000 metric tons of global warming pollution every year from 2016 onward.[29] (This savings estimate assumes that electric vehicles are purchased instead of conventional gasoline-powered vehicles that meet increasingly stringent federal fuel economy standards.) That's the equivalent of removing 123,000 of today's average vehicles from the road.[30]

The pollution reduction from those EVs will be much more dramatic if they receive their power from clean, renewable sources instead of from the current mix of power plants operating in the United States. In that case, emissions would be reduced by 1.96 million metric tons, the equivalent of removing 385,000 average vehicles from the road.[31] Table 2 shows state-by-state estimated pollution savings based on the Center for Automotive Research's state-level projects of vehicle sales.

Even greater savings could be achieved if policies to promote EVs result in more such vehicles hitting the road by 2015. Speeding up the rollout of electric vehicles to put 1 million such vehicles on the road by the end of 2015 would reduce global warming pollution by 1.34 million metric tons annually if the vehicles were charged from the nation's existing power plant mix, and would prevent 4.19 million metric tons of pollution if the vehicles were powered by renewable energy.

Table 2: Metric Tons of Global Warming Pollution Prevented Annually by Electric Vehicles Sold 2012-2015 in Two Generation Scenarios [32]

State	If Cars Are Powered from the Existing Electrical Grid	If Cars Are Powered with Renewable Electricity
AK	1,342	3,699
AL	3,028	13,968
AR	3,170	11,722
AZ	21,010	52,080
CA	189,862	470,594
CO	16,710	41,417
CT	12,379	34,131
DC	2,217	6,113
DE	2,110	5,819
FL	35,897	103,944
GA	7,385	34,064
HI	3,350	9,238
IA	2,841	16,485
ID	3,183	7,889
IL	7,795	74,898
IN	2,847	27,910
KS	5,862	14,521
KY	1,727	13,234
LA	2,870	10,947
MA	21,985	60,617
MD	16,293	48,949
ME	3,496	9,640
MI	3,656	35,304
MN	6,262	29,275
MO	5,627	25,329
MS	1,223	5,643

State	If Cars Are Powered from the Existing Electrical Grid	If Cars Are Powered with Renewable Electricity
MT	2,191	5,580
NC	10,726	49,477
ND	480	2,220
NE	1,497	7,335
NH	4,646	12,811
NJ	19,917	54,915
NM	5,757	14,269
NV	6,457	16,004
NY	38,371	105,798
OH	4,928	48,308
OK	5,072	12,581
OR	16,524	40,956
PA	19,584	66,553
RI	2,723	7,507
SC	3,761	17,348
SD	854	3,469
TN	4,470	20,847
TX	41,426	107,861
UT	5,089	12,614
VA	13,851	71,534
VT	2,556	7,047
WA	28,176	69,838
WI	3,877	32,045
WV	621	6,079
WY	1,090	2,723
U.S. Total	**628,773**	**1,963,152**

California has already established policies to increase the penetration of electric vehicles in that state by 2025, and states that have adopted California vehicle emission standards are likely to follow. The goal is to have 1.4 million electric vehicles and other zero-emission vehicles on the road by 2025.[33] That means that more than 15 percent of new vehicles sold in 2025 would need to be zero-emission or plug-in hybrid-electric vehicles. With such widespread use of electric cars, global warming emissions from vehicles would drop by 12 percent.[34]

Maximizing the Pollution Savings of Electric Vehicles

Replacing a conventional gasoline vehicle with an electric vehicle will reduce emissions of carbon dioxide and other pollutants. Cleaning up the power grid by adding clean, renewable energy sources will further increase the pollution prevention benefit of electric vehicles. At the same time, widespread use of electric vehicles can make the power grid more flexible and less reliant on dirty sources of energy.

Clean Electricity Makes Electric Vehicles Even Cleaner

Building new renewable electricity generating facilities to replace or supplement existing coal- or natural gas-fired power plants will lower the average amount of global warming pollution released by producing electricity.

The nation has sufficient capacity to charge electric vehicles today; the problem is that the mix of generating facilities includes many dirty sources of power.[35]

Wind and solar energy generate emissions-free electricity that can help clean up the electricity grid and reduce emissions from electric vehicles across the United States. The quantity of power produced by wind turbines varies with the speed of the wind, which is generally highest overnight.[36] That makes it particularly suitable for charging electric cars, which will mostly be charged in the evening (under the assumption that owners will plug them in on returning home from work) or at night (as a result of a conscious effort to ensure that charging takes place when electricity costs are lowest).[37]

Wind power has been proliferating rapidly in the United States; new wind installations in 2011 gave the nation 46,919 MW of wind capacity—a 17 percent increase since the end of 2010, and more than double the nation's wind capacity in 2007.[38] Continuing—and accelerating—that development of wind capacity could allow the nation's electricity grid to meet the additional demand occasioned by the large-scale rollout of electric cars without significantly increasing fossil fuel consumption by power plants.

If sources such as wind power come to produce most of the electricity used to power electric vehicles, the impact of electric vehicles on pollution would be much more dramatic. While a plug-in hybrid vehicle charging in the evening from the current average power mix of the U.S. electric grid would emit 32 percent less global warming pollution than a conventional gasoline car, the same car charging entirely from renewable energy would emit 78 percent less global warming pollution than the gasoline car.[39]

Electric Vehicles Can Store Clean Electricity and Make the Grid Cleaner

As electric cars become more common, their batteries will begin to offer the electrical grid something it has never before possessed—a modular, widely dispersed, large volume of storage capacity for power—potentially contributing to the ability to integrate greater amounts of solar and wind energy into the nation's electric system.

Electric cars can be used to help make electricity consumed for all purposes cleaner. By drawing as much of their power as possible from the cleanest and most efficient power plants, storing it in their batteries, and then feeding that power back into the grid during times of high demand, electric vehicles can make the power grid more flexible and less polluting.

At present, electricity production has to be closely matched to demand throughout the day. That means that while some large power plants run night and day, others are switched on and off to match the variation in demand that occurs over the course of 24 hours.

Electric cars—and their batteries—provide an alternative method for ensuring adequate power supply through the day. Batteries can be charged at off-peak hours, then discharge energy back into the grid to help meet midday demand surges.

The storage capacity provided by electric vehicle batteries can also help incorporate intermittent sources of power, like wind energy, into the grid. Denmark, which has led the world in developing wind power, plans to turn to electric cars to allow it to incorporate levels of wind power above what an unimproved grid would be capable of carrying into its electrical system.[40] In the future, a significant fleet of electric vehicles could allow the United States to do the same thing, making possible a cleaner electrical grid.

Electric Vehicle Technology Is Ready to Make an Impact

The significant increase of electric vehicles in retail markets anticipated for 2012 is the result of several factors. Car companies have invested in the vehicles with the knowledge that policymakers are looking to put cleaner cars on the road; consumer interest has been piqued by the popularity of hybrid cars; and some of the underlying technologies have become cheaper and more effective.

The electric cars on the market today, and entering the market in the near future, would not have been technically feasible as little as a few years ago. Rapid advances in battery technology, in particular, have made electric cars more affordable.

Between 1991 and 2005, for instance, the cost per unit energy of the lithium ion batteries used in electric cars fell by 80 percent, while the energy density of those batteries (the amount of energy that can be stored in a battery by weight) doubled.[41] Those trends may be accelerated by large-scale investment in advanced batteries worldwide, including through a significant infusion of American Reinvestment and Recovery Act funds in the United States, which have triggered a fierce competition between advanced battery manufacturers.[42] As battery makers compete to cut costs and develop better technology, electric cars will gain in performance and become less expensive.

The energy density and cost of batteries help determine two of the features of electric cars that consumers are most likely to care about—their price and their range. A crucial third feature, which will help determine the degree of flexibility that electric car owners have in planning their trips, is the time required to recharge electric cars. Current technology allows for relatively slow charging using chargers that can plug into a standard wall outlet, or significantly faster charging at specially designed charging stations. The Nissan Leaf, for instance, charges in 8 hours using a home charger that plugs into a high voltage outlet. The Leaf also can be charged to 80 percent of its battery capacity within 30 minutes using a special "quick charger."[43] A 30 minute charge time is short enough that a driver could recharge a battery most of the way while running errands. Charging technology is improving: the recently released Ford Focus EV charges in just over three hours using a 240 volt charger (similar to that used for a clothes dryer).[44]

Ultimately, researchers aim to reduce battery charging times to closer to the time required to refill a gasoline vehicle at the pump. Nissan researchers have been able to charge batteries within 10 minutes in the lab, although their technology is not yet ready for commercial deployment.[45] Researchers at the University of Illinois, meanwhile, have developed technology that can charge a car battery in "tens of seconds" in the lab.[46] Current charging technology allows EV owners to recharge their cars overnight, and is fast enough to enable recharging during a shopping trip or restaurant visit; further advances could allow drivers to recharge their vehicles in the same time it takes to fill a car at a gas station.

This combination of technological advances puts electric vehicles in a position to claim a significant share of the automobile market. Like all new technologies, electric vehicles will not enter and transform the market immediately. Even the most popular products take time to capture consumer attention, and manufacturers need time to expand production capacity. This is particularly true for products like automobiles, which are expensive, complicated to manufacture, and replaced only slowly (7-8 percent turnover per year).[47]

Initial sales figures for electric vehicles compare favorably to the figures for gasoline-electric hybrids like the Honda Insight and Toyota Prius from a decade earlier. In 2000, the first year that those vehicles were made available to customers in appreciable numbers, just over 9,300 hybrids were sold. Sales figures in the second year hybrids were available exceeded 20,000—a few thousand more units than electric vehicles sold in their first year on the market.[48]

Over the following decade, increasing demand for hybrids, improving technology, and growing production capacity combined to produce sales volumes much larger than during those initial years. Sales peaked in 2007, just before the nation entered a recession, at 352,000 units. [49] In total, 2,340,000 hybrids were sold between 2000 and the end of May 2012.[50]

Already, the pace of electric vehicle sales has increased, with sales from January through May 2012 totaling more than 13,000 vehicles.[51]

A wide range of electric vehicles are already on or shortly to enter the market. As these cars become widely available, consumers will have a choice between different brands, styles, and vehicle technologies, creating the opportunity for EVs to fill a range of niches in the automobile market.

Plug-in Hybrids

A number of plug-in hybrids have either already reached the U.S. market, or will become available in 2012 or shortly thereafter. A sample of the offerings either already available or scheduled for release in the near future includes:

- The **Chevrolet Volt** became available in late 2010, and has sold 15,000 units in the United States.[52] The Volt is a four-seat hatchback with an all-electric range of 35 miles. The car is a "series" hybrid, in which the gasoline engine does not connect directly to the wheels but instead powers a generator, which supplements the battery to drive the electric motor as needed.[53]

- The **Toyota Prius Plug-in Hybrid** was released in early 2012. The automaker aims to sell 16,000 Prius plug-ins in the first year the car is on the market. The car is a modified version of the Prius hatchback, with an all-electric range of 11 to 14 miles.[54]

- The **Ford C-Max Energi** is a five-passenger plug-in hybrid minivan scheduled for release in 2012 or 2013. It uses a "parallel" hybrid architecture, in which both the electric motor and the gasoline engine can power the wheels directly. Ford also plans to offer a midsize plug-in, the **Ford Fusion Energi**, beginning in late 2012.[55]

- The **Mitsubishi MiEV** is a mid-sized SUV, similar to the company's existing Outlander model, which offers a 30-mile all-electric range on a parallel hybrid drivetrain.[56]

Battery Electric Vehicles

Fully electric vehicles also broke into the U.S. automobile market in large numbers for the first time in 2011, as the Nissan Leaf sold 9,600 units.[57] The Leaf will soon be joined by other all-electric alternatives, including a range of different vehicle types.

- The **Nissan Leaf** has sold more than 12,000 units since its introduction in late 2010.[58] The automaker plans to begin producing its own batteries at a factory in Smyrna, Tennessee, in order to keep up with demand for the vehicle; the plant will have a capacity of 200,000 batteries a year.[59] The automaker intends to double its production of Leafs for the U.S. market in 2012. [60]

- Ford plans to offer the **Focus Electric**, a compact car, in the New York, New Jersey, and California markets during 2012, before scaling up to broader retail sales in future years.[61]

- The **Toyota Rav4 EV**, a battery electric version of the small SUV, will be offered to the public beginning in 2012. The automaker will also offer the small **Scion iQ EV** to fleet and car-sharing programs.[62]

- The **Honda Fit EV**, a compact car with an 82-mile range, will be offered in California and Oregon beginning in summer of 2012, before expanding to more markets in early 2013.

- The **Mitsubishi i** is a subcompact car with a range of 62 miles and is available to consumers now.[63]

Electric Vehicles Will Be Deployed Fastest Where Infrastructure and Policy Support Is Present

Some products work best in clusters. The first person in a given town to buy a car early in the twentieth century, for instance, would immediately have the benefit of a new transportation option. They would not, however, realize the full potential of their new purchase if no one else in the community followed their lead. A single car owner could not support the network of gas stations, paved roads, and parking facilities that makes car ownership so useful. Only after other local consumers also had invested in a car would the first purchaser receive the full benefits of their own vehicle.

The effect on one user of a product or service from others' use of the same product or service is referred to as a "network effect." In the case of electric cars (as with the original gasoline cars), the impact of the network effect is to make electric cars more valuable to their owners as more electric cars enter service, encouraging the development of charging stations and other support infrastructure and services.

This being the case, electric cars are likely to enter the market most quickly in places where local policy, public enthusiasm, and infrastructure availability are most favorable. Electric vehicles will be metropolitan vehicles first; large cities offer more destinations within the range of electric vehicles. Cities have also been the logical place to invest in public recharging stations for those times when drivers need to recharge their vehicles away from home (see Table 3).

Table 3: Top Ten States for Public Electric Vehicle Charging Stations by State as of March 2012[64]

State	Number of Charging Stations Installed
California	1,718
Washington	674
Texas	570
Michigan	480
Florida	475
Oregon	415
New York	367
Maryland	262
Illinois	245
North Carolina	211

Since cars are primarily used relatively close to home, city- and county-level policies can play a disproportionately large role in promoting the spread of electric cars.[65] Drivers will be more likely to choose an electric vehicle if they are confident that their driving experience will be simple and convenient. Policies that make it simpler to install charging equipment at home and that facilitate the installation of a large number of public charging stations will create an environment where electric vehicle drivers can have maximal flexibility in where they take their cars.

As electric car manufacturers make plans to begin selling their vehicles in the United States, they typically target a few initial markets, in order to take advantage of the benefits that concentration offers despite the small initial number of vehicles sold. Nissan, Ford, and GM all selected initial target markets for their first electric vehicles, including California because of the state's strong set of policies supporting electric vehicles, and the state's history of high consumer demand for hybrids.[66]

Cities, states, car companies, and the federal government have prepared the ground for adoption of electric vehicles by installing a growing number of charging stations nationwide. As of March 2012, the United States has more than 7,000 charging stations, with more planned and under construction.[67] (See Figure 1.) Several federal grant programs created by the American Reinvestment and Recovery Act (ARRA) have directed money toward installing electric vehicle chargers.

- The **Clean Cities Program** aims to reduce petroleum dependence in the transportation sector. Clean Cities grants funded by the ARRA have will lead to the construction of more than 1,600 chargers and the purchase of 600 electric vehicles for use in government fleets across multiple states. [68]

- The **EV Project**, seeded by a Department of Energy grant and administered by Electric Transportation Engineering Corporation (eTec), is installing 15,000 charging stations and subsidizing the purchase of 6,000 electric cars across Arizona, California, Tennessee, Texas, Oregon, Washington, and the District of Columbia. [69]

- **ChargePoint America**, sponsored by Coulomb Technologies and funded in part by an ARRA grant from the Department of Energy, is installing 5,000 chargers across ten metropolitan areas in California, Washington, Michigan, Texas, New York, Florida, and the District of Columbia. [70]

- Individual cities and private companies are moving ahead with their own charging infrastructure projects in places like Portland, Oregon; King County, Washington; and Houston, Texas. [71]

Figure 1: Existing and Planned Electric Vehicle Charging Stations in the Lower 48 States[72]

Policy Recommendations

Electric vehicles offer significant benefits in the form of decreased pollution and reduced dependence on petroleum for transportation. Policymakers on the local, state, and national level should aim to facilitate the quick deployment and widespread adoption of electric vehicles.

Public policies have been effective at promoting alternative vehicles. The Center for Automotive Research found that the top 10 states for hybrid vehicle registrations per capita had 40 percent more public sector policies and 20 percent more private sector policies (such as favorable insurance treatment) than the U.S. average. [73]

States and municipalities should adopt policies to facilitate the adoption of electric vehicles. Among the tools they can use are:

- **Installation of charging stations:** Drivers will be able to use their electric vehicles for more trips, and for longer outings, once a network of public charging stations is in place in their area. Installing charging stations will help jump-start the market for electric vehicles, and is a tool that a number of leading cities have adopted to promote electric vehicle ownership.

- **Simplification of permitting:** Early experiences have suggested that extensive permitting processes to install home or business EV chargers can be an annoyance and deterrent for potential customers. Leading cities are implementing simple permit processes requiring only one or two days for processing.[74]

- **Fleet vehicle purchases:** Government and corporate vehicle fleets are good candidates for early acquisition of electric vehicles. Because of their large size, they can often trigger network effects through their purchases alone, and can take advantage of economies of scale in installing and purchasing chargers, while saving on the substantial fuel costs associated with operating a large vehicle fleet. Fleet purchases have played a vital role in the early deployment of electric vehicles.[75]

- **Financial incentives:** Some state governments and the federal government have instituted tax incentives or grants for purchasers of electric vehicles.

These incentives help consumers overcome the higher upfront cost of current models of electric vehicles. Six states currently offer grants to electric car purchasers, and 14 states and the federal government offer tax incentives for buying an electric vehicle.[76]

- **Convenience incentives:** Cities and states can also incentivize electric vehicle ownership by, for instance, allowing electric vehicles to have access to convenient parking spaces. Twenty-one states offer at least one convenience incentive.[77]

In addition, the federal government should **continue to invest in research** to drive down the cost and improve the performance of electric vehicles into the future. Electric vehicles are becoming a viable alternative to conventional vehicles because of improved technology, and policymakers should continue to promote research into more effective batteries and other technologies. This can take place either through publicly funded basic and applied research—of the sort performed at the various national laboratories and at a number of universities—or through loans to companies working to bring new technologies to market.

As electric vehicles enter the market, a larger and larger share of the energy used by automobiles will come from the electric grid, rather than from gasoline. This offers an opportunity to expand on the pollution benefits of displacing gasoline.

To achieve the greatest pollution benefits from the deployment of electric cars, policymakers should:

- **Promote renewable energy** and aim to replace fossil-fueled power plants. States can take advantage of a number of tools, such as renewable electricity standards and incentives for renewable power generation to promote renewable energy.

- **Work towards developing a "smart grid,"** which would enable electricity grid managers to more effectively balance variable demands and sources

Public Support of Private Research

Supporting private companies in order to promote technological advances will not always lead to success—nor should it. In a competitive market, some companies often fail even as performance improves and costs fall. Take the advanced battery market, for instance; the falling battery prices caused by advances in production techniques and cost-cutting competition between production firms will benefit electric car manufacturers and consumers, but the effect on the battery industry itself will likely be to winnow the ranks of producers.

Current worldwide battery manufacturing capacity is sufficient to supply twice the number of electric cars that automakers have committed to build by 2013.[78] Given that imbalance, it is possible that some number of battery firms—in the U.S. and abroad—will fail due to insufficient sales to keep them afloat. The correct test for whether the public investment has succeeded, however, is not the success or failure of any single firm, but instead the progress towards widespread availability of a beneficial technology—the reason the research was funded initially.

of generation and enable electricity customers to save money by turning on appliances when power is cheapest. A smart grid incorporating access to a large number of EV batteries will increase the reliability of electricity service and enable higher penetration of renewable generation sources like wind and solar power.

Methodology

To model the impact of electric car deployment, we paired electric car sales projections from the Center for Automotive Research with figures for well-to-wheels pollution (i.e., the pollution produced during the entire process of fuel production and driving) produced by electric cars from a 2010 Argonne National Laboratory report (see below). Pollution and oil savings benefits were calculated by subtracting the pollution produced, and oil consumed, by the projected population of electric cars in each state from the pollution produced and oil consumed by the conventional cars that they would replace.

We assumed that:

- The electric cars sold between 2012 and 2015 would break down as follows:
    - 50 percent battery electric vehicles
    - 25 percent plug-in hybrids with a 40 mile all-electric range
    - 25 percent plug-in hybrids with a 10 mile all-electric range

- Electric cars would replace conventional gasoline cars that would otherwise have been purchased in the same year and used similarly.

- An average vehicle (whether internal combustion (ICE) or plug-in hybid (PHEV)) is driven 11,300 miles per year (figure from U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Table 8.9: Average Annual Miles per Household Vehicle by Vehicle Age" in *Transportation Energy Data Book*, *Edition 30*, 25 June 2011.

- Vehicles charging in the different regions of the U.S. electric grid, as defined by the Energy Information Administration in its *Annual Energy Outlook 2007*, will draw their electricity from marginal power providers that would roughly match those of regions profiled in Amgad Elgowainy, Jeongwoo Han, Leslie Poch, Michael Wang, Anant Vyas, Matthew Mahalik, and Aymeric Rousseau, Argonne National Laboratory Energy Systems Division, *Well-to-Wheels Analysis of Energy Use and Greenhouse Gas Emissions of Plug-in Hybrid Electric Vehicles*, June 2010 as detailed in Table 4.

Table 4: Electricity Grid Regions Paired with Example Regions from Elgowainy et al., 2010

Grid Region	Generation Profile Match
ECAR	MAIN (IL)
ERCOT	WECC – CA
MAAC	NPCC-NY
MAIN	MAIN (IL)
MAPP	WECC – CA
NPCC-NY	NPCC-NY
NPCC-NE	NPCC-NY
FRCC	NPCC-NY
SERC	NPCC-NY
SPP	WECC – CA
WECC-NW	WECC – CA
WECC-RMP/ANM	WECC – CA
WECC-CA	WECC – CA

- The on-road well-to-wheels global warming pollution emissions of an ICE vehicle would be 33.5 percent higher than its EPA rated carbon dioxide emissions, in accordance with the values used in modeling by Elgowainy et al., 2010. The difference reflects both higher emissions in real world driving conditions and emissions from "upstream" sources like oil refineries and fuel transportation.
- Gasoline vehicles sold in any given year will meet the fuel economy and carbon dioxide pollution standards set by the EPA and National Highway Traffic Safety Administration for that year.
- The performance of electric cars will remain constant over time (an extremely conservative assumption, since electric cars are likely to benefit from many of the same technological improvements that will make conventional cars cleaner, as well as from continued advances in battery technology).
- Plug-in hybrid vehicles would be used in the mix of charge-depleting and charge-sustaining modes modeled by Elgowainy et al. and used to produce Figure 6.14 and other figures of that report, and would be charged in an unconstrained fashion (i.e., would be plugged in when they returned from their last trip of the day, without intervention technology that might delay charging until a more favorable time). Battery electric vehicles were modeled by combining figures from Elgowainy et al. (particularly as pertains to the pollution intensity of electricity used to charge vehicles) with figures on battery electric vehicle performance from the 2011 Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET 1 2011) model published by Argonne National Laboratory, 14 October 2011.

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