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TRANSPORT ELECTRIFICATION PANEL (TEP) MEMBERS

Gurminder Bedi (Chair)
Ford Motor Company (Retired)

Michael Brylawski
Bright Automotive

John German
International Council on Clean Transportation

Dr. Sara Hajiamiri
Pardee RAND Graduate School

Dr. Donald Hillebrand
Argonne National Laboratory

Dr. Kara Kockelman
University of Texas at Austin

Michael Ligett
North Carolina State University

Dr. Virginia McConnell
Resources for the Future

Paul Mitchell
Energy Systems Network

Nick Nigro
Pew Center on Global Climate Change

Brett Smith
Center for Automotive Research

Michael Tinskey
Ford Motor Company

Dr. Thomas Walton
Defour Group

TEP FACULTY AND STAFF

Dr. John D. Graham
Dean, School of Public and Environmental Affairs, Indiana University

Dr. Sanya Carley
Assistant Professor, School of Public and Environmental Affairs, Indiana University

Chris Crookham
MPA Student, School of Public and Environmental Affairs, Indiana University

Devin Hartman
MPA and MS Student, School of Public and Environmental Affairs, Indiana University

Dr. Bradley Lane
Assistant Professor, Institute for Policy and Economic Development, University of Texas at El Paso

Natalie Messer
MPA Student, School of Public and Environmental Affairs, Indiana University

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Pew Center on Global Climate Change

Pete Hardigan
Ford Motor Company

Dr. Eladio Knipping
Electric Power Research Institute

Dr. Kenneth Kurani
University of California – Davis

Mark Perry
Nissan Motor Company

Dr. Stephen Popiel
Synovate Motoresearch

Rich Steinberg
BMW

Dr. Kristin Zimmerman
General Motors Company

EXECUTIVE SUMMARY

Despite the rapid economic growth of China and India, the United States is by far the world's largest consumer of oil, accounting for more than 20% of the 87 million barrels per day that are used around the world. America's dependence on oil has contributed to a suite of economic, security, geopolitical, and environmental problems, and, thus, there is growing national interest in reducing petroleum use.

The transportation sector of the U.S. economy is a focal point for policymakers because it accounts for 27% of U.S. greenhouse gas emissions (the gases linked to global climate change) and 70% of U.S. petroleum consumption. A majority of the oil in the transport sector is used to power light-duty vehicles such as cars, sport-utility vehicles, vans, and pickup trucks. Previous efforts to find alternatives to oil have not been highly successful, and thus the U.S. transportation system remains more than 90% dependent on petroleum. Absent effective countermeasures, oil consumption rates and greenhouse gas emissions are projected to grow in the United States and globally in the decades to come.

A variety of alternatives to petroleum are under consideration, including biofuels, natural gas, hydrogen, and electricity. Each of these alternatives has benefits and limitations in different applications, and each may have some role to play in the decades ahead. But the requirements for any viable alternative to gasoline are becoming more demanding. Gasoline engines are becoming significantly more fuel-efficient due to innovative refinements, while conventional hybrid engines and advanced diesel engines are increasing their market shares.

Plug-in electric vehicles (PEVs) are nonetheless coming to dealer showrooms. General Motors Corporation is offering the 2011 Chevrolet Volt, while Nissan Corporation is offering the 2011 LEAF, vehicles that rely primarily or exclusively on electricity. Some plug-in vehicles are considered "battery electric vehicles" (BEVs), since they rely entirely on electricity (e.g., the LEAF), while others are called "plug-in hybrid electric vehicles" (PHEVs), since they still rely partly on conventional fuels (gasoline and diesel). Both BEVs and PHEVs are called "plug-in electric vehicles" because they are designed to be recharged by plugging into the power grid. Note that a conventional hybrid electric vehicle (HEV), such as the Toyota Prius, is powered by batteries and gasoline but is not considered a PEV because it does not have the plug-in feature.

Powering vehicles with electricity is of significant interest because innovation in battery technology, if dramatic enough, could constitute a breakthrough in the search for ways to reduce petroleum use. In 2009, the U.S. federal government highlighted electricity as a promising alternative to petroleum for transport purposes. An official domestic goal of putting one million plug-in electric vehicles on the road by 2015 was established, and a variety of public policies to encourage electrification has been implemented by federal, state, and local governments.

Some government support for the introduction of PEVs into the marketplace is warranted because firms are unable to capture all the benefits that their research and development (R&D) efforts produce. Suppliers and manufacturers are likely to underinvest in innovative initiatives to offer PEVs. Private underinvestment in R&D is the primary justification for public policy designed to stimulate private R&D through instruments such as low-volume production grants and loan guarantees, tax incentives, and public-private partnerships.

This report examines public policies toward PEVs, taking into account the promise and limitations of PEVs, recent improvements in battery technology, market dynamics, and the proliferation of policies around the world that promote the use of PEVs. Our focus is primarily near term (i.e., 2011-25), recognizing that the transportation electrification process will evolve in stages based on the learning that occurs in the years and decades ahead. The report represents the views of the Transport Electrification Panel (TEP), a group of experts from multiple disciplines and organizations commissioned by the Indiana University School of Public and Environmental Affairs (IU SPEA). TEP's work has been supported by a team of graduate students and faculty from IU SPEA, but the findings and recommendations in this report are strictly those of TEP.

Report Findings

1. *The U.S. PEV Industry in the Global Market.* Virtually all major vehicle manufacturers and several start-up companies are offering—or are planning to offer soon—a PEV for sale in the U.S. market. PEV offerings have also been announced throughout Europe and Asia. While U.S. automakers are working on PEVs, the U.S. electric vehicle industry lags behind other regions—particularly Asia—in the areas of battery manufacturing, supply chain development, and raw materials production. PEVs may never dominate the mass vehicle market, but it is possible—some experts say likely—that they will capture a significant share (5-15%) of the market over the next 15 to 20 years.

2. *Policy Instruments.* Recent public policies in the United States and other countries have improved the prospects for initial commercialization of PEVs. These policies include generous tax credits for consumers and producers, new regulations of vehicle manufacturers, special access to high occupancy vehicle (HOV) lanes and city parking, loan guarantees and subsidies for companies in the PEV industry, grants for recharging infrastructure, and federal R&D support for more advanced battery technologies. California's Zero Emission Vehicle (ZEV) program has been an influential driver of the recent product offerings by some automakers. Many countries have established short-term vehicle production targets comparable to those of the United States. Policies in some European countries, China, and Japan focus directly on promoting PEVs, while the European Union (EU) has focused on technology-neutral measures (e.g., carbon emissions limitations on new vehicle sales). Japan and South Korea have emerged as leaders in battery R&D, with the United States also becoming a significant R&D supporter.

3. *National Goal of One Million Plug-In Electric Vehicles.* When the U.S. government established the goal of putting one million PEVs on the road by 2015, both the future of the technology and the financial capability of the U.S. auto industry were uncertain. The production intentions of automakers are currently insufficient to meet the 2015 goal, and even the current plans for production volume may not be met. Automakers could ramp up PEV production if consumer demand proves to be larger than expected. However, consumer demand for PEVs is quite uncertain and, barring another global spike in oil prices, may be limited to a minor percentage of new vehicle purchasers (e.g., early technology adopters and relatively affluent urban consumers interested in a "green" commuter car).

4. *Market Drivers.* Four market factors, each of which can be influenced by public policy, present the greatest potential for altering the competitive position of PEVs in the vehicle market: (1) energy prices; (2) battery characteristics (safety, reliability, and production costs); (3) the availability of convenient and affordable recharging infrastructure; and (4) the pace of progress with PEVs compared to competing technologies, such as refinements to the internal combustion engine, conventional hybrids, advanced biofuels, natural gas vehicles, and fuel cell vehicles.

5. *Early Adopters vs. Mainstream Car Buyers.* One key reason that mass commercialization of PEVs may proceed slowly over the next decade is that mainstream retail purchasers of new vehicles differ from the relatively small number of enthusiastic "early adopters." Mainstream car buyers are careful about investing in new technologies that are not fully understood. There are a variety of uncertainties about exactly how much money will be saved by PEVs (savings depend on uncertain forecasts of fuel and electricity prices), how reliable and safe the batteries will be, how convenient and costly it will be to recharge a PEV, how easy it will be to have the vehicle serviced, and how difficult it will be to resell the vehicle. Although proponents of PEVs are making progress in resolving these uncertainties, consumers will ask many questions before purchasing a PEV and will wait to hear from others who choose to experiment with a PEV.

6. *The Need for "Truth in Advertising."* Initial consumer experiences with PEVs—their real-world driving range, cost, safety, reliability, and ease of recharging and resale—will exert a significant influence over mainstream consumers' perceptions of PEVs. If customer expectations are inflated (by automakers, dealers, power companies, environmental groups, and/or government officials) relative to what is actually experienced, the reputational damage to the technology could be significant and possibly irreparable. News stories are already describing the "hype" associated with the campaign for PEVs.

7. *BEVs vs. PHEVS.* BEVs have some clear advantages over PHEVs: they offer greater potential for energy security benefits by eliminating the vehicle's use of petroleum; they have no tailpipe emissions; they eliminate the complexity and cost of the internal combustion engine; and the electric drive system is relatively simple to design, produce, and service. However, the obstacles to mass commercialization of BEVs are even greater than the obstacles for PHEVs. Given the high cost of battery production, a BEV that approaches affordability (with generous tax credits) has a driving range of about 70-100 miles on a full charge. The battery pack takes a long time to fully recharge (usually overnight), and even using an expensive commercial recharger takes considerably longer than refilling a standard gasoline tank. Although typical daily travel patterns in the United States lie well within the 100-mile range, most vehicle purchasers desire a full-function vehicle that can meet their predictable peak travel demands (i.e., their longest trips, such as weekend and holiday road trips). With its battery pack complemented by a small gasoline or diesel engine, a PHEV can make use of the existing refueling infrastructure to achieve driving ranges of 300 miles by featuring conventional refueling capabilities in addition to recharging the battery. An affordable BEV cannot match this range or speed of refueling, so BEVs may not achieve mass commercialization until there are breakthroughs in battery technology, though they may succeed in niche markets such as commuter vehicles for affluent multi-vehicle households or urban pick-up and delivery vehicles.

8. *Recharging Infrastructure.* Both PHEVs and BEVs are designed with the intention of using residential recharging as the primary refueling method, but BEVs also depend on the emergence of some recharging stations in the community. The obstacles to residential recharging are less challenging than community recharging, but more imperative to overcome. The biggest barriers to residential recharging are faced by those consumers who would otherwise find PEVs most attractive: urban dwellers with short commutes, who often lack garages or convenient access to an electrical outlet. Additionally, most municipal regulations and permitting processes are not yet designed with PEVs in mind and present a bureaucratic obstacle to the timely and efficient installation of residential recharging units. Workplace recharging will also be helpful and is already sponsored by some employers, but will occur less frequently than residential recharging. Retail outlets may have commercial incentives to install recharging facilities if sufficient demand develops, but the short-term need for community recharging is limited, installation remains expensive, and bureaucratic and technological obstacles persist.

9. *Battery Innovation.* There are promising prospects for advancements in battery technology that improve performance and reduce costs, and breakthroughs in advanced battery chemistries remain a distinct possibility. Significant cost reductions in battery technology have already been achieved. Additional battery R&D may achieve even greater cost reductions, perhaps more significant than the cost reductions expected through economies of scale and "learning by doing" in the production process. While refinements of lithium-ion battery technology may prove sufficient for mass commercialization of PHEVs, a new type of energy storage will likely be required so that BEVs can satisfy the cost and range preferences of mainstream consumers.

10. *Environmental Impacts.* A comprehensive environmental evaluation of PEVs must consider the fact that production of electricity will generate risks to the environment that will vary in nature and magnitudes depending on the source of power. The potential impacts of PEVs on climate change are of particular concern. Given the current mix of electricity sources in the United States, use of a PEV will emit far fewer greenhouse gases than the current average gasoline engine, but may not be better than HEVs that do not need to be recharged. As long as electricity production depends heavily on high-carbon energy sources, the net effect of PEVs on greenhouse gases will be limited and will vary by region. As electricity production shifts to lower carbon-emitting sources, the environmental promise of PEVs will be enhanced significantly.

Recommendations

1. *Technology-Neutral Policies*. Policymakers should generally pursue energy security and environmental goals through technology-neutral policies, thereby allowing the marketplace for fuels and vehicles to determine which technologies are superior. The following fuel-saving policy instruments are typically considered technology-neutral: a gasoline tax; a national fuel efficiency standard that allows manufacturers to trade compliance credits; and a "feebate" incentive system for fuel efficiency, where buyers of high-mileage cars are awarded a rebate while buyers of low-mileage cars pay a fee. Policymakers must recognize that innovative, emerging technologies are at different stages along their learning and cost-reduction curves, and it is difficult for innovators, including commercial "first movers," to fully capture the benefits of their risk-taking. Thus, technology-neutral public policies will not always be technology-neutral in their practical effects. Some technology-specific policies are needed to allow emerging technologies to compete with mature technologies. If technology-neutral policies are not adopted, perhaps due to political opposition, and instead technology-specific policies are enacted, they should be designed to be as cost-effective as possible. Before any policies are enacted that might seem to promote PEVs specifically, the benefits of fleet electrification need to be compared to those from competing technologies. Given the technological and market unknowns, it may be wise for policymakers and businesses to invest in a mix of emerging technologies (non-PEVs and PEVs) until R&D and real-world experience establish which technologies are superior in specific applications. Any targeted public assistance for PEVs should be limited in both duration and production volumes. These programs should also be monitored and evaluated regularly to ensure accountability and effectiveness.

2. *National Demonstration of PEVs*. A federally supported, national PEV demonstration program should be implemented to help overcome the information barriers faced by the PEV industry today. A de facto demonstration is already underway as private and governmental efforts prepare target communities for PEVs. Yet these efforts have not been combined and coordinated in a focused national program aimed at "learning by doing." In order to resolve uncertainties about PEVs, it is crucial that the demonstrations gather data from consumers, dealers, manufacturers, utilities, retailers, and municipalities. Without key data, the opportunity to learn about the real-world experience with PEVs—successes, burdens, and mistakes—will be foregone, and unnecessary public uncertainty, confusion, and debate will continue. In the design of a cost-effective national demonstration program, the following program characteristics should be considered:
    - A focus on a limited number of designated communities (five to 20, depending on community size) with a range of climates, demographic and housing characteristics, public transit systems, and electric utility and regulatory systems.
    - A strong partnership between national laboratories, universities, municipalities, and private actors is needed to collect high-quality data. The demonstration communities, and especially the data-gathering exercises within them, must be large enough to support statistically significant sample sizes, and the original data and findings must be shared widely with researchers and practitioners.
    - In order for a demonstration community to provide useful data, it should have as many of the following characteristics as possible:
        - streamlined permitting procedures to facilitate recharging;
        - time-of-use data gathering and electricity pricing capability;
        - a priority placed on residential recharging infrastructure coupled with some workplace and community recharging;
        - guidance materials available regarding niche fleet markets where PEVs may be particularly promising because routes are short and recharging can be performed at a central location (e.g., urban pick-up and delivery vehicles);
        - data gathering activity on vehicle purchasing and leasing, driving patterns, servicing and recharging behaviors, and the evolution of public perceptions and attitudes; and

- o action plans and evaluation activities that coordinate the vital roles of motorists, car dealers, automakers and suppliers, utilities, regulators, fleet buyers, and universities.

Such a demonstration program should be monitored by independent analysts to ensure that community demonstrations do not proliferate to the point that they represent a bias toward PEVs.

3. *Global Leadership Position in Technology, Manufacturing, and Public Policy*. The U.S. automotive, battery, and electric power industries, in collaboration with the U.S. government and universities, should seek to establish a global leadership position in electric mobility, especially in advanced energy storage technologies and production of batteries and related components. Constructive steps have already been taken toward fostering a U.S.-based supply chain for PEVs and expanding R&D into advanced batteries and other power train components. The track record of policies toward PEVs needs to be evaluated and, where necessary, refined as technology and market conditions change. Thus, the national demonstration and R&D program should be seen not just as a strategy to pursue worthy energy security and environmental goals, but also as a strategy to help revitalize the U.S. manufacturing sector.

4. *International Collaboration*. Although the focus should be on advancing U.S. leadership and competitiveness in this dynamic field, there is also a need for some international collaboration. Historically, different vehicle standards have been a barrier to international trade, making it difficult for companies to transfer innovations from one national market to another. The EU, Asia, and North America are adopting somewhat different technical procedures and public policies toward PEVs. Areas ripe for cooperation include codes and standards for recharging, approaches to measuring vehicle fuel efficiency, and emissions measurement, including test conditions. A regular international exchange of information about the formulation of successful PEV demonstrations and public policies is also appropriate. Since China and the United States have some common national interests in reducing petroleum use and have facilitated constructive corporate partnerships in vehicle technology and production, the China-U.S. dialogue on PEVs should be encouraged to continue, assuming intellectual property rights are respected.

5. *Cost-Effective Consumer Incentive Programs*. For investors in emerging technologies, there can be a "valley of death" between the market acceptance of early adopters and widespread commercialization. Without some public assistance through this valley, emerging technologies with long-term promise may be discarded prematurely. In this regard, PHEVs may be closer than BEVs to overcoming the valley, since the current energy storage capabilities for BEVs are inadequate. While generous volume-limited tax credits have already been established for consumers who purchase a PEV (e.g., up to $7,500 at the federal level and an additional $5,000 in a few states), the following targeted, cost-effective measures to boost consumer demand for PEVs are worthy of consideration:
   - government and commercial fleet purchases;
   - PEV access to HOV lanes and parking in congested urban areas;
   - battery warranty adjustments or guarantees; and
   - targeted public information programs to dispel myths and reduce confusion.

6. *Support for Recharging Infrastructure*. Private investments in recharging infrastructure may prove to be too small to support adequate demonstrations due to high initial costs for recharging infrastructure, few "first mover" advantages, relatively low energy prices in the United States, long payback periods, and uncertainty about the volume of future PEVs on the road. Significant public funding of recharging infrastructure has already been appropriated, and it is not yet clear whether more funding is necessary. Since some retailers (e.g., shopping malls) may have adequate business incentives to offer recharging stations to help attract and retain customers, relatively little infusion of public funds should be aimed at community recharging facilities. As additional public cost-sharing of recharging is provided, the cost-effectiveness criterion suggests that the highest priority should be residential recharging, followed by stations at workplaces and then community stations. Excessive spending on community stations may result in severely underutilized infrastructure, which can damage public support for PEVs.

7. *Modernizing the Electric Power System*. Even a partial shift from petroleum to electricity as a transportation fuel will have ramifications for the operation and growth of the electric power system. Detailed knowledge of the power grid is required to ensure that outages are avoided. To optimize the benefits of electrification, public policies should be adopted to:

    - accelerate "smart grid" research, standards, and implementation;
    - expand the availability of lower electricity prices during off-peak periods to enhance consumers' willingness to charge their vehicles at night, and include continuous time-of-use pricing adjustments where acceptable;
    - increase the availability of metering, recharging, and vehicle technologies that will enable these time-of-use adjustments to electricity prices; and
    - encourage or require enhanced efficiency and the movement toward a cleaner power generation system in order to reduce upstream emissions associated with PEVs in the form of greenhouse gases and conventional pollutants.

8. *Long-Term R&D Commitments*. Lithium-ion batteries may never have adequate energy density to independently power a household's primary multi-purpose vehicle. Although there have been significant improvements in battery technology since the 1990s, policymakers should consider a large increase in federal R&D investments into innovative battery chemistries, prototyping, and manufacturing processes. A broader selection of R&D grantees, with even more vigorous competition, is appropriate compared to past practices. Sustained investment in R&D, including both public and private funds, is crucial as the United States seeks to establish a leadership position in the growing global market for advanced battery technologies and related components. The potential spillover benefits in the economy from R&D and manufacturing leadership deserve serious consideration by policymakers, even though public R&D decisions will be made in a troubled federal fiscal situation. In order to determine the appropriate scale of R&D expansion, the expected payoffs from long-term R&D investments in energy storage techniques should be compared to the anticipated payoffs from R&D investments in other advanced fuels and propulsion systems.

Countries around the world are jockeying for position in the emerging PEV industry. The time for the United States to secure a leadership position in the global market for PEVs is now. This report provides an expert panel's view of how the United States can secure this role in a cost-effective manner.

Table of Contents

List of Acronyms

BEV	Battery electric vehicle
CARB	California Air Resources Board
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
EIB	European Investment Bank
EPA	U.S. Environmental Protection Agency
EU	European Union
GDP	Gross domestic product
GHG	Greenhouse gas
GM	General Motors Company
HEV	Hybrid electric vehicle
NEV	Neighborhood electric vehicle
NiMH	Nickel-metal hydride
OPEC	Organization of the Petroleum Exporting Countries
PEV	Plug-in electric vehicle
PHEV	Plug-in hybrid electric vehicle
R&D	Research and development
SET	Strategic Energy Technology
SUV	Sport-utility vehicle
V2G	Vehicle-to-grid
ZEV	Zero-Emission Vehicle

PREFACE

A major experiment with plug-in electric vehicles (PEVs) is about to unfold around the world. While the design of the propulsion systems vary considerably (including the precise battery technology), a common feature of these vehicles is that the consumer will be expected to recharge the vehicle at home, at work, and/or at a publicly available recharging station.

The stakes in the outcome of this experiment are considerable. Automakers and suppliers, taxpayers, and venture capitalists have made multi-billion dollar investments in the gamble that PEVs will prove to be commercially viable. But the gamble is not simply a financial one. By reducing global dependence on petroleum, PEVs may help address some of the globe's most pressing risks: energy insecurity, environmental damages from oil spills, urban air pollution, and global climate change.

If PEVs prove to be commercially viable and if U.S. companies and workers are leaders in this emerging industry, the economic payoff for the manufacturing sector of the U.S. economy, and the economy as a whole, could be enormous. If, instead, Asian and European firms dominate the emerging sector, the future of America's troubled manufacturing sector could become even bleaker. Thus, interest in the electric vehicle industry is tied to broader concerns about the future of manufacturing in the United States and the global competitiveness of American industry.

Despite their promise, there are many unanswered questions and concerns about PEVs. Will the limited range of these vehicles satisfy the perceived needs of consumers? Will battery packs be reliable, durable, and safe when a vehicle is used under extreme conditions and as a vehicle ages? Will local communities make sufficient investments in recharging infrastructure to facilitate widespread use of PEVs? Will PEVs be an attractive financial proposition when accounting for expensive battery packs, the cost of recharging infrastructure, and the anticipated financial savings from using electricity instead of gasoline? Even if PEVs reduce pollution at the tailpipe of the vehicle, will they result in more pollution at electric power plants? Since the per-mile cost of electricity is currently much lower than gasoline, will owners of PEVs contribute to congestion, pollution, and crashes by driving more miles on an annual basis than they would with a gasoline-powered vehicle? The answers to all these questions will not be known with precision until some real-world experience with PEVs materializes.

Recognizing the importance of this issue, the Indiana University School of Public and Environmental Affairs (IU SPEA) commissioned an expert panel, the Transportation Electrification Panel (TEP), in the spring of 2010 to examine the future of PEVs in the United States. TEP convened twice in Washington, D.C., May 10–11 and October 18–19, 2010. The panel received input from academics as well as from representatives of industry, government, and non-profit organizations. Staffed by graduate students and faculty at IU SPEA, TEP was tasked with the following charge:

1. assess whether the U.S. government's goal of putting one million plug-in electric vehicles on the road by 2015 can be achieved given current federal and state policies and market dynamics;
2. suggest constructive policy innovations that will advance the prospects of transport electrification in a cost-effective manner, thereby overcoming the economic and non-economic obstacles to commercialization; and
3. identify and evaluate the beneficial and adverse effects, including the unintended risks and costs, which could result from the increasing policy interest in transport electrification and examine their policy ramifications.

IU SPEA has funded and staffed the work of TEP, but the recommendations in this report are those of TEP and do not necessarily represent the viewpoints of SPEA, IU, or the state of Indiana. Nor should the recommendations be attributed to the organizations that employ the members of TEP, since the members have participated in this report as individuals, without any expectation that their employer would review or approve of the content of this report.

The purpose of this report is to inform the federal, state, and local policymakers who are considering enactment of policies that will influence the future of the plug-in electric vehicle industry. The report will also be of interest to leaders of foreign governments. We trust that the report will provide useful insight for the wide range of stakeholders with an interest in the issue, such as environmental and consumer organizations; manufacturers who assemble and dealers who sell motor vehicles; suppliers of batteries, electrical systems, lithium, and other parts of a propulsion system or vehicle; providers of electric power and their regulators; and reporters, opinion leaders, and members of the general public.

February 2, 2011
John D. Graham, Ph.D.
Dean
School of Public and Environmental Affairs
Indiana University
Bloomington, Indiana

INTRODUCTION

Early History of the Electric Car

Interest in electric propulsion of cars and trucks is on the rise throughout the global automobile industry, but the idea is certainly not new. The electric car was invented in the 1830s, decades before the invention of gasoline and diesel engines. By the turn of the century (1900), the number of automobiles powered by electricity in the United States was almost double the number powered by gasoline (though both were outnumbered by steam-powered vehicles).[1] The commercial success of electric vehicles was greater in the United States than in any other country. However, U.S. sales peaked in 1912 and steadily declined to near-extinction in the following decade.[2]

Historians attribute the initial demise of the electric vehicle to a variety of factors, including their lack of horsepower, the improved availability of gasoline, and the demand for longer-distance vehicles.[3] By the 1920s, improved road networks between American cities were stimulating consumer demand for longer-range vehicles.[4] Due to their short range, electric cars sold in the United States from 1900 to 1930 were owned primarily by affluent urban residents.

The decline of real oil prices also played a role. The discovery of accessible crude oil in California, Oklahoma, and Texas caused the price of gasoline to become more affordable for ordinary Americans. Innovations also helped the gasoline engine. The invention of the muffler in 1897 led to a reduction in engine noise, while invention of the electric starter in 1912 eliminated the need for the hand crank. While progress with the electric car was also occurring, three stumbling blocks were persistent: low top speed, short range on a single charge, and relatively high cost of production. Henry Ford's mass production of the internal combustion engine allowed gasoline cars to be sold for $500–$1,000, while the typical electric car—even one without frills—was typically priced well above $1,000. The gasoline-powered model became the engine of preference for automobiles.

By 1935, the electric automobile had virtually disappeared, and interest in electric propulsion would not return for 25 years.

Unlike the 1900–30 period when consumer demand spurred interest in the electric car, the resurgence of interest in electrification that began in 1960 is attributed primarily to public concerns about air quality. Poor air quality in urban areas was a key factor, especially in smog-ridden Los Angeles and other cities where cars were popular, geography was unfavorable to dispersion of pollution, and mass transit systems had become impractical or underfinanced.[5] With strong public support, environmentalists advocated alternative approaches to fueling cars that would reduce or even eliminate pollution from the tailpipes of cars.

In 1966, Congress introduced the first bills supporting electric cars as a method of air pollution control.[6] The California Air Resources Board (CARB) issued a variety of regulations aimed at spurring cleaner engines, including electric cars and other so-called "zero-emission vehicles" (ZEVs).[7] The U.S. Environmental Protection Agency (EPA) also issued regulations to spur cleaner engines but EPA rules often lagged behind those issued by CARB.[8]

The world oil crises of the 1970s, especially the quadrupling of nominal oil prices following the 1973–74 Arab oil embargo, caused politicians in the United States to search for alternative ways of fueling America's economy. Since America's electricity sector was to be weaned off oil in favor of coal and natural gas, the electric car was seen as a positive step toward America's "energy independence." In 1975, for example, the U.S. Postal Service purchased 350 electric delivery jeeps from American Motors Corporation, jeeps with a top speed of 50 miles per hour, a maximum range of 40 miles, and a 10-hour recharging time.[9] However, the high cost of batteries and short driving range remained insurmountable barriers to commercial success.[10]

The combination of CARB regulations, the national Clean Air Act Amendments of 1990, and the national Energy Policy Act of 1992 caused most major vehicle manufacturers to offer a limited number of electric cars and/or trucks for sale, especially in California. From 1992–98, for example, the following electric vehicles were offered on a limited basis: Ford's Ecostar utility van, an electric version of the Ford Ranger pickup truck, GM's EV1 two-seat sports car, an electric version of the Chevy S-10, an electric version of the Toyota RAV4 SUV, the Honda EV Plus sedan, Chrysler's EPIC minivan, and the Nissan Altra EV station wagon.[11]

None of these vehicles was a commercial success. Sales of electric cars were hampered by their high prices (typically $30,000–$40,000 before tax breaks), a small consumer market, a sustained period of low oil prices in the 1990s (with fuel prices as low as $1.00 per gallon), and judicial and technical setbacks for CARB as it sought to implement and enforce the ambitious ZEV program. By 2000, interest in electric-drive vehicles in the United States had transferred to a few bold start-up companies (e.g., Tesla), while GM, Ford, Chrysler, Honda, and Toyota saw limited prospects.

Drivers of Renewed Interest

In the last decade, a variety of factors have converged to stimulate reconsideration of electricity as an alternative fuel for the transportation sector of the U.S. economy. Energy security concerns and environmental concerns and regulations are key drivers of this renewed interest in transport electrification.

Energy Security Concerns

Since the world oil crisis of 1973–74, the industrial and utility sectors of the U.S. economy have dramatically reduced their dependence on petroleum through enhanced energy efficiency and conversion to other energy sources (largely natural gas and coal). However, with the exception of a modest increase in the use of biofuels, little progress has been made in reducing oil use in the transport sector. There have been major gains in vehicle fuel efficiency since 1975, but they have been essentially nullified by the prevalence of heavier cars due to consumer demand for size, luxury equipment, and performance.[12] PEVs are seen as a promising tool to reduce oil dependence, as electricity production in the United States is virtually free of petroleum (petroleum constituted 1% of U.S. net power generation in 2009).[13]

Transportation is critical to the functioning of any economy. With more than 90% of its transportation energy coming from petroleum-based fuels,[14] the United States is vulnerable to any sources of volatility in the world oil market. For example, sudden and large increases in world oil prices have occurred previously due to wars in the Middle East, unrest in Nigeria, unexpected refinery shutdowns, and perceptions among market actors that oil shortages might emerge in the future. The United States does not import much oil from the Middle East, but our oil-based economy is whipsawed by instabilities in the oil-rich region because oil is a commodity whose price is determined in a global market. Thus, oil consumption from either domestic or imported sources creates vulnerability to oil supply disruptions.

OPEC accounts for about 40% of the world's yearly oil production (about 87 million barrels per day were demanded worldwide in 2010[15]), and this dependence is projected to increase to more than 50% by 2025.[16] While OPEC is believed to have two million barrels per day in spare capacity (mostly in Saudi Arabia), the Saudis have historically been quite ineffective in modulating the use of their spare capacity to prevent large swings in world oil prices. Thus, even if Saudi Arabia is seen as a country sympathetic to U.S. interests and the Saudis shared an interest in more stable oil prices, they have not demonstrated an ability to accomplish sustained price stability. OPEC may actually prefer price volatility because it undermines the confidence of investors in alternatives to petroleum.[17] It is notable that OPEC countries are gradually gaining more control of refining operations as well as oil production facilities, which means they are acquiring more ability to control diesel and gasoline prices around the world.[18]

While the economic impacts of oil dependence are significant, the geopolitical ramifications are arguably more important, and they are certainly salient to leading policymakers in the U.S. Department of State and Department of Defense. Since the United States is a large consumer of oil (accounting for more than 20% of global demand,[19] a share that is decreasing due to growth of developing countries), U.S. consumption helps boost the world price of oil, which in turn enlarges the flow of money from oil-consuming countries to oil-exporting countries. Foreign policy specialists, including former CIA Chief R. James Woolsey,[20] contend that this large transfer of wealth—sometimes managed through huge "sovereign wealth funds"[21]—produces foreign policy consequences that are harmful to U.S. interests and undercuts the values and ideals that the United States is striving to promote around the world.

A task force of the Council on Foreign Relations recently summarized some of the adverse geopolitical ramifications.[22] Oil dependence induces political realignments that inhibit the United States from forming international partnerships to achieve common objectives. Venezuela, for example, uses its wealth to dispense patronage around South America.[23] Oil money certainly strengthened the hand of Russian Prime Minister Vladimir Putin, who consolidated his power, rolled back the tentative steps to democracy in Moscow, and opposed U.S. interests in the independence efforts of Kosovo.[24]

Another perverse effect of oil dependency arises when oil-consuming countries alter their policies to better accommodate the interests of countries who act as their oil suppliers. High oil prices (and the appearance or perception of scarce supplies) diminish political confidence in the ability of open markets to ensure secure supply, leading oil importers to forge political arrangements outside commercial terms. These arrangements lead to special political relationships that can pose challenges to the advancement of U.S. interests in foreign policy. For example, achieving consensus among American allies regarding sanctions on Iran is difficult due to allies' reliance on Iran's oil supply.[25]

There are concerns that wealth transfers to oil exporting countries have been an indirect source of funds for terrorists hostile to U.S. interests. Tracing the dollars is not easy, because there is no transparent record of how almost half of the wealth transfers are ultimately expended.[26] But evidence suggests that oil revenues have helped finance some of the organized military opposition to U.S. forces in Iraq and Afghanistan.[27] Based on this intelligence, it has been stated that the United States finances both sides of its military conflicts.[28]

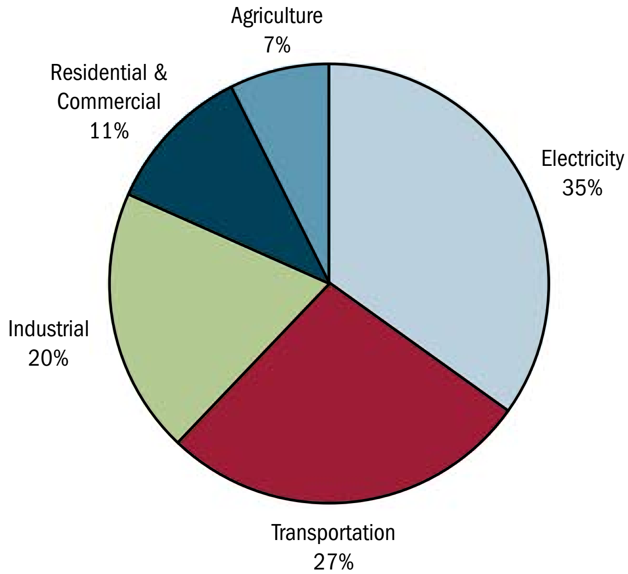
High oil prices are also believed to cause oil-exporting countries to be less democratic and more autocratic than they would otherwise be. There are certainly exceptions to this association (e.g., Norway and perhaps Mexico), but a statistical study of 113 states from 1971–97 found a clear inverse relationship between reliance on oil or mineral wealth and democratic governance.[29] The causal pathways are complex. When regimes are flush in oil revenue, they can keep the public content through low taxes and generous spending on services while quietly repressing social groups who oppose the regime.[30] While some studies have found a significant link between oil exports and the risk of civil war,[31,32,33] other studies find lower levels of anti-state protests and civil war,[34] perhaps because oil-rich autocrats can buy a degree of domestic tranquility (at least in the short run).

In summary, American opinion leaders and policymakers increasingly view U.S. oil dependence as damaging to U.S. interests in foreign policy. The lay public has shared this view for several decades. Given that increasing use of PEVs can reduce dependence on petroleum, the geopolitical ramifications of oil dependence will be a persistent and growing driver of political interest in PEVs.

Environmental Impacts and Regulations

The environmental ramifications of oil-based transportation are also a major driver of interest in the future of PEVs. If transportation can shift from petroleum-based fuels to electric power, PEVs may have the effect of reducing water contamination from oil drilling, reducing the frequency of oil spills from off-shore facilities and tankers, reducing smog and soot in the air, and slowing the rate of global climate change by curbing greenhouse gas (GHG) emissions. In some cases, environmental regulations that address these concerns are already acting as a driver in favor of PEVs.

Figure 1: U.S. Greenhouse Gas Emissions by Sector (2008)



Source: Pew Center on Global Climate Change, Transportation Emissions in the United States. Accessed Jan 22, 2011. Adapted from: U.S. Environmental Protection Agency (EPA), 2010. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008 [http://www.epa.gov/climatechange/emissions/usinventoryreport.html]. Available from: http://www.pewclimate.org/technology/overview/transportation

Environmental concerns about oil dependence reached a critical point in the summer of 2010 with the ecological damage wrought by the British Petroleum Deepwater Horizon oil spill. Tanker accidents also act as high-profile consequences of oil dependence, although more mundane spills occur frequently from pipeline leaks. While the United States can also act to reduce the likelihood of spills with stricter regulation, reducing the demand for petroleum in the United States would also have a beneficial effect.

In California, a key driver toward PEVs in the 1990s and a modest driver today, is the desire to curb tailpipe emissions that contribute to smog and soot in urban air.[35] Mobile sources also emit air toxics that may increase the chance that exposed populations will develop cancer and suffer some damage to immune, reproductive, neurological, developmental, and respiratory systems.[36] While smog, soot, and air toxics remain a serious concern, recent U.S. regulations of fuels and engines (combined with regulations from CARB) have caused a dramatic decline in the rate of tailpipe emissions.

More recently, the environmental case for PEVs has shifted to their promising role as a technology to reduce the greenhouse gas emissions that are linked to global climate change. The U.S. transportation sector is responsible for about 27% of GHG emissions nationwide,[37] (see Figure 1) and the use of passenger cars and light trucks is one of the most rapidly growing sources of GHGs. Currently, passenger vehicles contribute more than half of all domestic transportation sector emissions.[38] Without GHG controls on the U.S. transportation sector, it is likely that GHG emissions will continue to grow (even if modest progress is made in reducing GHGs from stationary sources). PEVs can be a part of a technology portfolio to reduce GHG emissions from the transportation sector.*

The development of new regulatory programs to improve vehicle fuel economy and reduce carbon dioxide emissions is a key driver of recent manufacturer interest in offering PEVs. The ZEV program administered by CARB is scheduled for refinement this year.[39] It is widely expected that compliance with new ZEV rules will entail some limited offerings of PEVs by all high-volume manufacturers seeking to do business in California.[40]

The U.S. federal government has issued ambitious fuel economy and carbon standards for new cars and light trucks produced through model year 2016.[41] A new process is also underway to consider how much to tighten these regulations for new vehicles sold in the 2017–25 timeframe. In the near term, manufacturers are encouraged to comply by offering PEVs since, under federal rules, each manufacturer can sell 200,000–300,000 PEVs without any compliance penalty for the upstream GHG emissions that these vehicles generate.

*A discussion on net emission impacts of PEVs that account for "upstream" emissions increases from power plants is in the "Recent Market Developments" section, see p. 42.

California's Zero Emission Vehicle Program

In 1990, the California Air Resources Board (CARB) mandated that auto companies' sales fleets include zero emission vehicles (ZEVs) at 2% of their California sales mix by 1998, increasing to 10% of sales by 2003. At the time, expectations were that ZEVs would primarily be battery-powered. In 1996, auto companies began leasing PEVs to the public and agencies. However, the ZEV mandate encountered difficulties, and automakers stopped producing PEVs. On the heels of a lawsuit by automakers, the mandate was adjusted to allow ZEV credits for non-ZEVs and development of new technology ZEVs in 2003.

The policy revisions also included a point system for increased flexibility in compliance. Three emissions categories qualify for credits: a gold level for ZEVs, a silver level for zero emission enabling technologies (including HEVs, PHEVs, and vehicles fueled by compressed natural gas), and a bronze level for gasoline vehicles with exceptionally low exhaust and evaporative emissions. Full implementation of the current mandate would result in 67,500 zero or near-zero emission vehicles on the road by 2012. *Note*: The 2015 requirements will be updated this year.

Sources: California Air Resources Board, March 17, 2010. *Zero-Emission Vehicle Legal and Regulatory Activities—Background*. Available from: http://www.arb.ca.gov/msprog/zevprog/background.htm

California Air Resources Board, Sept 21, 2009. *Overview of the California Zero Emission Vehicle Program*. Available from: http://www.arb.ca.gov/msprog/zevprog/factsheets/overview.pdf

Webb, A. Aug 2, 2010. "California's Zero-Emission Credits Give Startup EV Makers a Boost." *Automotive News*, pg. 16.

Enablers of Electric Propulsion

Certain technological and economic factors have improved the commercial prospects for PEVs. These factors fall into three categories: battery technology, smart grid technology, and energy economics.

Battery Technology

Advances in computer and battery technology have already exerted a significant impact on the automotive industry by helping to revitalize the hybrid-electric powertrain system, which was first offered at the turn of the 20th century by Tesla, Porsche, and Edison. In the late 1990s, nickel-metal hydride (NiMH) batteries were selected to propel the Toyota Prius, the small hybrid car with distinctive aerodynamics that is now in its third generation of commercial success.[42]

The nickel-metal hydride electric vehicle battery was invented in Japan by Dr. Masahiko Oshitani of GS Yuasa Corporation and in the United States by Stanford R. Ovshinsky of Energy Conversion Devices.[43] Due to the assignment of patent rights and subsequent corporate deals, Toyota and General Motors Corporation developed strong initial positions in the global battery industry. But Toyota did better than GM in finding some commercial success. In early 2007, the Prius was the seventh best-selling vehicle in America, and in some U.S. cities (e.g., San Francisco and Portland, Oregon) it was the top-selling car.[44] In recent years, Prius sales in the United States have averaged 150,000 per year with a total of more than 800,000 sold in the United States since 2000.[45]

Despite the commercial success of the Prius, the revitalization of the hybrid electric vehicle (HEV) has not yet had any more than a modest impact on the overall U.S. vehicle market. The original Honda Insight and the larger, performance-oriented Honda Accord Hybrid were terminated due to poor sales.[46] Among mid-sized and large sedans, the hybrid remains a small player. The Ford Escape and Toyota Highlander SUVs are offered with hybrid options, but fewer than 20% of buyers choose to pay the premium price for the hybrid.[47] All of GM's hybrid offerings to date have been commercially unsuccessful, and no manufacturer has successfully offered a hybrid engine in the large market for pickup trucks.

Looking over the past decade, the number of hybrid offerings in the U.S. market has proliferated from the Toyota Prius and Honda Insight in 2000 to more than 15 in 2011.[48] Most forecasters project steady (or even rapid) growth of the HEV market through 2025, but in 2009, HEVs accounted for less than 3% of vehicle sales in the United States.[49] In fact, the Prius accounts for almost two-thirds of all HEVs sold in the United States since 2000, and survey data suggest that the Prius experience will not be easy to replicate (e.g., more than 70% of Prius buyers earned above $100,000 per year, and Prius buyers were often trading down from luxury vehicles such as the Audi A6, the BMW X3, and the Acura TL).[50] The Prius has proven successful in a niche market with distinctive characteristics from the mainstream market. PEVs may have early success in this niche market, but widespread commercialization of PEVs will require success with a broader range of buyers.

For commercial success of PEVs, major advances in battery technology are needed to ensure affordable cost, safety, durability, and excellent performance. The development of lithium-ion batteries is a particularly promising start because their cost of production has declined markedly in the last decade (in the service of non-vehicle applications), and their chemistry offers performance advantages regarding power and energy density optimization.* Lithium-ion batteries typically have half the weight and twice the power of the nickel batteries that have been used in previous electric vehicle ventures.[51] As a result, when Toyota offers a plug-in version of the Toyota Prius in 2012, it is expected to have lithium-ion instead of nickel batteries.[52]

The world's first mass-production line for automobile lithium-ion batteries opened in Japan in April 2009 as a joint venture of GS Yuasa Corporation and Mitsubishi Motors.[53] Called "Lithium Energy Japan," the venture's premise is that a manganese-based chemistry can be less expensive and more stable than the cobalt-based varieties of lithium batteries championed by Yuasa's competitors.[54] The world's top producer of lithium batteries, Sanyo Electric Company of Japan (a subsidiary of Toyota-affiliated Panasonic Corporation), will supply lithium-ion batteries for the plug-in Prius.[55]

Smart Grid Technology

Electricity distribution occurs through an electric grid, which is an interconnected network that delivers power from suppliers to consumers. There are some noted inefficiencies with electric distribution. The current form of the grid has contributed to brownouts and blackouts, most notoriously the blackout that occurred in the Northeast from overload during a heat wave in August 2003.

One solution to these issues is a "smart grid," which incorporates advanced transmission, distribution, metering, and consumer technologies. Although the phrase "smart grid" has no universal definition, it tends to encompass two-way communication between the user of electricity and the energy provider, enhanced second-by-second monitoring of electric loads, and the capability to manage two-way electricity flows that go from the provider to the user and from the user back to the provider.

The pace of penetration of smart grid technologies is uncertain, but they are being deployed around the world today and seem inevitable in the long run. The current electric infrastructure is aging and will require substantial investment in upgrades and expansions in coming decades.[56] The need for smart grid management is growing due to the increasing role of intermittent renewable energy sources such as wind and solar power that depend on weather conditions and the growing number of independent power producers that own alternative energy systems that must be integrated into the grid. The smart grid, if designed and operated properly, can be expected to enhance both system efficiency and reliability.

Before the concept of the smart grid, there were fears that widespread use of PEVs would strain the grid because PEV owners would drive home after work and plug their vehicles into the grid during the high-demand period from 4 p.m. to 7 p.m. on weekdays. Peak power demands determine how many new power plants must be built. Moreover, when a plant's capacity is strained, disruptions and blackouts are more likely to occur.

The deployment of smart grid technologies in coming decades may facilitate the commercialization of PEVs in several ways. Smart meters and recharging software will enable precise monitoring of electricity flows between batteries and the grid. Smart chargers can manage the power drawn by PEVs, helping to ensure battery recharging occurs outside high-demand times. If utilities accompany smart grid technologies with innovative time-of-day pricing options, vehicle owners will have incentives to charge their batteries during the hours with lower demand for energy (usually overnight). Though not required for PEV commercialization, smart grid technologies could also provide the infrastructure—the distribution technologies, power conversion technologies, and consumer-utility interface systems—to help PEVs achieve higher rates of commercialization. At the least, smart grid technologies can enable the deployment of future electricity technologies

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*Detailed information on battery costs in the following section, "Recent Market Developments," see pp. 36-37.

that may prove useful in later stages of PEV commercialization, such as quick recharging technologies and two-way power flow.

Energy Economics

The economics of PEVs entail a comparison between the price of electricity and the price of gasoline. Both prices can change, but oil prices (which influence retail prices of gasoline and diesel fuel) have been more unpredictable. Oil price volatility undermines investment in alternative fuels. While the nominal price of fuel at the pump was well below $2 per gallon for most of the 1990s, it has been persistently above $2 per gallon (with periodic spikes above $3 per gallon) since 2000.* Despite the severe global recession of 2007–09, nominal fuel prices in the United States have remained well above $2 per gallon and, in early 2011, again passed $3 per gallon.

Most forecasts call for rising fuel prices over the next few decades as the global economy recovers and as China and India claim progressively larger shares of global oil supplies. OPEC's continued influence in the petroleum market suggests that the world price of oil will continue to be inflated compared to what a competitive global market for oil would produce. And, when the United States, European, and Asian economies are fully recovered and growing again, OPEC's ability to push the world price of oil over $100 per barrel will be buttressed.

The prices of gasoline and diesel fuel are tightly linked to the world price of oil, but electricity prices in the United States are only weakly related to oil. Electricity prices are determined in regional markets and are related to the prices of natural gas and coal, which account for about 70% of U.S. electricity production.[57] The cost of electricity for electric drive is around 2 to 4 cents per mile, which varies with regional electricity prices.[58] Consequently, U.S. electricity prices are typically one-fourth to one-half of gasoline prices when the two prices are compared on an energy-equivalent basis. Most forecasts suggest that this spread will continue (and probably increase) in the decades ahead.** However, the infrastructure for driving is funded by the gasoline tax, while electricity is not currently subjected to any such tax. If PEV consumers had to pay their fair share of infrastructure costs, the gap between the costs of these two fuel sources would narrow. Overall, the basic trends in energy economics appear to be favorable to the commercialization of PEVs.

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*Historical, current, and forecasted future petroleum prices are available from the Energy Information Administration at: http://www.eia.doe.gov/dnav/pet/pet_pri_top.asp

**The EIA projects a 29% increase in gasoline prices from 2007 to 2020 and a 39% increase by 2030. From 2007 levels, the EIA projects electricity prices to increase 3% by 2020 and 14% by 2030. See: Energy Information Administration. 2009. *Annual Energy Outlook 2009 With Projections to 2030*. Available from: http://www.eia.doe.gov/oiaf/aeo/pdf/0383(2009).pdf

RECENT MARKET DEVELOPMENTS

The U.S. PEV industry has grown from one premium sports car in 2009 to two additional passenger sedans in 2010 and will add at least 11 new models over the next two years. Table 1 lists the companies that have announced intentions to produce at least one PEV for the U.S. market in the foreseeable future. However, it is important to note that announced production plans can change rapidly based on market conditions, and not all product plans are announced well in advance of product offerings.

The PEV industry is comprised of an interesting mix of established and relatively new market players. Interest in PEVs is uneven among the top 10 global vehicle manufacturers (see Table 2). Of the top 10, only three firms (Nissan, the French firm PSA, and GM) plan to produce more than 10,000 PEVs annually by the end of 2011.[59] By way of comparison, new light-duty vehicle sales in the United States are projected to be around 12 million in 2011.[60] Some start-up firms are striving to move faster than many major manufacturers in bringing PEVs to the market while several large, global manufacturers (Toyota, Honda, and Volkswagen) have hesitated to offer PEVs and have not yet committed to significant production volumes.

Toyota and Honda are innovative companies. Indeed, they are pioneers of the conventional HEVs that are gaining market share in the United States and globally. Yet both have been cautious about the commercial future of PEVs.

In the public debate about PEVs, Toyota has emphasized that conventional HEVs have more near-term promise than PEVs. Only recently did Toyota announce that it would produce a PHEV version of the Prius by 2012.[61] Toyota also announced plans to develop a BEV, but few specifics have yet been released.[62]

Similarly, as recently as October 2008, Honda was expressing no public interest in PEVs while expanding investments in conventional hybrids, hydrogen-powered fuel cell vehicles, and natural-gas powered vehicles.[63] Indeed, Honda's CEO argued publicly in 2007 that PHEVs are too expensive and do not deliver sufficient environmental benefits. Honda shifted direction by announcing in 2010 that it would produce both a PHEV and a BEV.[64] But Honda emphasized that its offering of PEVs is motivated by regulatory considerations, such as compliance with California's Zero Emission Vehicle program.[65]

Volkswagen has ambitious plans to quadruple its sales of cars in the United States by 2018, but PEVs were not central to that plan until very recently. Its focus seemed to be on advanced diesel engines.[66] In fact, the VW Group chairman said in 2009 that he did not expect PEVs to have a major market share for 15 to 20 years, and VW's plan was efficiency improvements to gasoline and diesel engines.[67] Yet VW has also hedged its bets. The company debuted a BEV at the 2009 Frankfurt Auto Show and has established 2013 as a date for introduction of this vehicle and several other electric models (see Table 1) into select U.S. markets.[68]

Ford has also announced plans to offer PEVs (e.g., the electric Ford Focus, a PHEV, and an electric version of the Transit Connect van) through its global platform for all new vehicles.[69] However, this plan for PEVs is a part of a diversified investment strategy that includes major improvements to the gasoline engine (Ford's "EcoBoost" program), more conventional hybrids (in addition to the Ford Escape Hybrid SUV), and greater deployment of diesel engines in its strong and diverse pick-up truck program.

Automakers recognize that California's ZEV program appears to be here to stay. In fact, the ZEV requirements are expected to be updated in 2011, with early indications that ZEV compliance credits will be more generous for BEVs than for PHEVs. Given this regulatory environment, any high-volume auto company interested in California's lucrative market is essentially required to offer some sort of PEV in the years ahead.[70]

Recognizing the difficulty of breaking into the mass retail market for cars, PEV start-ups have sought to find niche markets. It may be no accident that the first BEV to hit American roads in the post-1990 period was the Roadster, a luxury sports car from Silicon Valley's Tesla Motors with a high price tag and impressive performance statistics. Tesla's most prominent

Table 1: Plans for PEVs in the U.S. Market

Car Company	*PHEV*	*BEV*	*Models*	*Timeline*	*Planned Production Output*
Audi[1]	Yes	Yes	e-tron, A1 E-Tron	2012	"Limited"; "Small build"
BMW[2]	No	Yes	MINI-E, Active-E, Megacity	Megacity: 2013 MINI-E and Active-E in pilot lease programs currently	Unknown
BYD[3]	Yes	Yes	E6, S6DM	E6: 2012 (pilot testing in L.A. began in 2010)	Unknown
CODA Automotive[4]	No	Yes	CODA Sedan	2011	14,000 cars within 12 months of debut
Chrysler-Fiat[5]	No	Yes	Fiat 500	2012	Unknown
Daimler[6]	No	Yes	Smart ED Fortwo	2012	1,500 globally in 2011, series production in 2012
Fisker Automotive	Yes	No	Karma, Nina	Karma: spring 2011[7] Nina: mid-2012[8]	Karma: 15,000 annually[9]
Ford	Yes	Yes	Focus BEV, Transit Connect Electric, unnamed PHEV	Transit Connect Electric: began in late 2010[10] Focus BEV: 2011 Unnamed PHEV: 2012[11]	Transit Connect Electric: 600-700 annually beginning in April 2011[12] Focus BEV: 5,000-10,000 units annually[13]
GM[14]	Yes	No	Volt	In serial production	2011: 10-15,000 units 2012: up to 60,000 units

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Table 1 (cont'd): Plans for PEVs in the U.S. Market

Car Company	*PHEV*	*BEV*	*Models*	*Timeline*	*Planned Production Output*
Honda[15]	Yes	Yes	Unknown	2012	Unknown
Mitsubishi	Yes	Yes	iMiEV, PX-MiEV	i-MiEV: 2011[16] PX-MiEV: 2013[17]	Unknown
Navistar[18]	No	Yes	eStar	In serial production	Unknown
Nissan[19]	No	Yes	LEAF, NV200, Infiniti EV	LEAF: In serial production	LEAF: 500,000/year globally by 2012
Smith Electric[20]	No	Yes	Newton	In serial production	Capacity of 30 per week as of 2008
Tesla	No	Yes	Roadster, Model S	Roadster: in serial production Model S: 2012[21]	Roadster: 1,200 annually[22] Model S: 20,000 annually
TH!NK	No	Yes	City EV	Current fleet sales underway, retail serial production by summer 2012[23]	300 in U.S. by early 2011[24]
Toyota[25]	Yes	Yes	Prius PHEV, Unnamed BEV	2012	Prius PHEV: "tens of thousands" annually
Volkswagen[26]	Yes	Yes	Golf Twin Drive, Golf blue-e-motion/E-Up, all-electric Jetta	Golf Twin Drive: test fleet in 2011 Full production of all planned PEVs: 2013	Unknown
ZAP[27]	No	Yes	Alias	Unknown	Unknown, currently taking orders for limited edition version

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[21]LaMonica, M. May 21, 2010. *Tesla CEO: Model S to be 'platform' for other cars.* CNET. Available from: http://news.cnet.com/8301-11128_3-20005583-54.html

[22]Berman, B. March 9, 2010. *Tesla Roadster.* PlugInCars.com. Available from: http://www.plugincars.com/tesla-roadster/review

[23]Motavalli, J. January 13, 2011. *Norwegian EV Automaker Starts Production in Indiana*. BNET. Available from: http://www.bnet.com/blog/electric-cars/norwegian-ev-automaker-starts-production-in-indiana/2979

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[25]Toyota Motor Corporation. August 25, 2010. *Summary of Fifth Toyota Environmental Action Plan (FY2011-FY2015)*. http://www2.toyota.co.jp/en/news/10/08/0825b.html

[26]Yanca, J. May 2010. "Volkswagen Confirms Hybrid Golf, Jetta, and Passat; Electrics to Follow." *Car and Driver*. Available from: http://www.caranddriver.com/news/car/10q2/volkswagen_confirms_hybrid_golf_jetta_and_passat_electrics_to_follow-car_news

[27]ZAP. April 29, 2010. *Jonway to Manufacture ZAP's Alias Electric Sports Vehicle in China.* PR Newswire. Available from: http://www.prnewswire.com/news-releases/jonway-to-manufacture-zaps-alias-electric-sports-vehicle-in-china-92404579.html

Table 2: OICA 2009 World Ranking of Manufacturers*

Rank	*Manufacturer*	*Vehicles Produced*
1	Toyota	7,234,439
2	GM	6,459,053
3	Volkswagen	6,067,208
4	Ford	4,685,394
5	Hyundai	4,645,776
6	PSA	3,042,311
7	Honda	3,012,637
8	Nissan	2,744,562
9	Fiat	2,460,222
10	Suzuki	2,387,537
11	Renault	2,296,009
12	Daimler	1,447,953
13	Chana Automobile	1,425,777
14	BMW	1,258,417
15	Mazda	984,520

**World Ranking of Manufacturers Year 2009.* Organisation Internationale des Constructeurs d'Automobiles (International Organization of Motor Vehicle Manufacturers). Available from: http://oica.net/wp-content/uploads/ranking-2009.pdf

competitor is Fisker Automotive, another Silicon Valley start-up. Fisker's first vehicle is the Karma, a PHEV luxury sports car with a 50-mile electric range, which is set to launch later this year.[71] Since the batteries for PEVs are expensive but can enhance performance, the sports car market is a logical place for start-ups to find interested buyers.

An alternative niche market is mini-cars that are used regularly on trips with short ranges, usually in a planned community or city. The neighborhood electric vehicle (NEV) is a golf cart-like vehicle popular in many communities of senior citizens, which has already proven to be a successful niche market for battery-operated vehicles.

Urban mini-cars are also a key niche market. The Norwegian company TH!NK plans to bring its City EV, a two-seat urban car, to the New York City market and is already selling the vehicles in Norway, Austria, and the Netherlands.[72] In India, two companies are going head-to-head in the small, electric, low-cost car market. Tata has announced plans for an electric version of the world's cheapest car, the Nano, while Tara International countered with the Tiny, an electric mini-car to be offered for 1 rupee less than the Nano.[73]

Another promising application for PEVs is the urban delivery vehicle, a niche market within the large commercial truck and van sector. Buyers are spurred by desires to reduce noise and emissions in crowded urban areas and to reduce fuel costs, thanks in part to long periods of idle-off operation. Fixed routes and centralized recharging opportunities add to the appeal. This market for PEVs is so attractive that some of the PEVs designed for commercial truck use are beating passenger car applications to the market. The all-electric version of Ford's popular Transit Connect van won the 2010 North American Truck of the Year Award.[74] Smith Electric has been producing large electric vans for delivery purposes since 2009 and has sold them to large fleet buyers like Frito-Lay, which plans to have 170 electric trucks in its fleet by 2011.[75] Navistar's eStar is being used in Federal Express fleets.[76] Phoenix Motorcars has developed an all-wheel drive electric pick-up truck for fleet applications.[77]

Not all new market participants are sticking to niche applications of PEVs. BYD, a Chinese battery manufacturer, has entered the auto manufacturing world with an ambitious plan to compete directly with the offerings of GM and Nissan. BYD has some financial investment from Warren Buffet, as well as its own new battery chemistry—the Fe battery—that extends the car's range and allows a smaller battery to power a larger car.[78] BYD began production of the world's first mass-produced PHEV, the F3DM, in December 2008, only five years after entering the auto business.[79] BYD also has an all-electric model, the E6, which it plans to start selling in the United States in 2012, to be followed by a PHEV SUV called the S6DM. [80] However, the company has earned a reputation for setting ambitious goals that it is not always able to meet. Meanwhile, three-year-old start-up Coda Automotive is bringing an all-electric sedan to the U.S. market starting in 2011 on the heels of the rollout of the Nissan LEAF.[81] The car has a higher price tag than the LEAF, but Coda claims it has a longer and more reliable range.[82]

Forecasting future sales of PEVs is a guessing game. While sales are expected to grow rapidly over the next five years (domestically and globally), most global forecasts suggest limited production volume over the next two decades (see Table 3). Since the PEV sales growth curve will likely have a high upward slope through at least 2015, the number of PEVs on the road in 2015 will be primarily determined by the last two years of production. It does not appear that one million PEVs

Nissan LEAF

Type of PEV:	BEV
Advertised all-electric range:	100 miles
EPA rating of all-electric range:	73 miles[1]
Price (before any tax credits):	$32,780, for LEAF SV $33,720 for LEAF SL
Lease Price (36 months, accounts for federal tax credit of $7,500):	$349/month for LEAF SV $379/month for LEAF SL
Seats:	5
Doors:	5
Top Speed:	90 mph
0-60 mph Time:	Under 10 seconds[2]
Total Battery Capacity:	24kWh lithium-ion
Annual Production:	500,000 global production by 2012[3]
Battery Warranty:	8 years/100,000 miles

Chevrolet Volt

Type of PEV:	PHEV
Advertised all-electric range:	35 miles
EPA rating of all-electric range:	35 miles[4]
Price (before any tax credits):	$41,000
Lease Price (36 months, accounts for federal tax credit of $7,500):	$350/month
Seats:	4
Doors:	5
Top Speed:	100 mph[5]
Time from 0-60 mph:	8-9 seconds[6]
Total Battery Capacity:	16kWh lithium-ion
Annual Production:	10-15,000 in 2011; 60,000 by 2012[7]
Battery Warranty:	8 years/100,000 miles

Source: All details are from manufacturer Web sites as of January 15, 2011 unless otherwise noted.

[1] Chappell, L. November 22, 2010. *EPA rates the Nissan Leaf at 99 mpg and reduces range estimate*. Automotive News at Autoweek. Available from: http://www.autoweek.com/article/20101122/GREEN/101129960

[2] Lavric, D. July 27, 2010. *First Drive: 2011 Nissan Leaf doesn't change the game, just the players.* Autoblog. Available from: http://www.autoblog.com/2010/07/27/2011-nissan-leaf-first-drive-road-test-review/

[3] Ohnsman, A. July 26, 2010. *Nissan Sells 500 Nissan LEAF Electric Vehicles to Enterprise for Rental Fleet Use*. Bloomberg. Available from: http://www.bloomberg.com/news/2010-07-27/nissan-sells-500-leaf-electric-vehicles-to-enterprise-for-rental-fleet-use.html

[4] Kranz, R. November 24, 2010. *EPA rates Volt, 'all-electric' mpg at 93, range at 35 miles.* Automotive News at Autoweek. Available from: http://www.autoweek.com/article/20101124/GREEN/101129933

[5] "2011 Chevrolet Volt." *U.S. News and World Report*. Last updated January 1, 2011. Available from: http://usnews.rankingsandreviews.com/cars-trucks/Chevrolet_Volt/

[6] AutoblogGreen Staff. August 24, 2010. Video: Translogic tests Chevy Volt, reveals Mountain Mode and 0-60 time. AutoblogGreen. Availabe from: http://green.autoblog.com/2010/08/24/video-translogic-tests-chevy-volt-reveals-mountain-mode-and-0/

[7] Doggett, S. October 15, 2010. *GM Says Annual Production of Chevy Volt Plug-in Hybrid Could Hit 60,000 by 2012.* Green Car Advisor at Edmunds.com. Available from: http://blogs.edmunds.com/greencaradvisor/2010/10/gm-says-annual-production-of-chevy-volt-plug-in-hybrid-could-hit-60000-by-2012.html

will be sold in the United States by 2015 given current production plans and the available forecasts, but the goal could be surpassed within a few years thereafter.

In summary, the PEV industry is developing in what may seem to be an uneven and unusual way, with commercial vehicles, mini-cars, and luxury sports models coming into production before the technology is aimed at the mainstream consumer. Such a beginning should be expected given the realities of the auto industry and characteristics of PEVs. Therefore, after a summary of the findings from this section, this report turns to an exploration of the demand-side and supply-side issues that complicate the future of the PEV industry.

Table 3. Select Global and U.S. PEV Forecasts

Goldman Sachs[1] (July 2010)	PEVs will be about 4% of global light-duty vehicle sales by 2020. · PHEVs: 10,000 units (2010) to 2 million (2020) · BEVs: 20,000 units (2010) to 1.7 million (2020)
Pike Research[2] (September 2010)	PEV sales totaling 3.2 million vehicles worldwide between 2010 and 2015 and a compound annual growth rate of 106%. · China: 888,000 PEVs sold by 2015 (27% of global market), by far largest BEV market · U.S.: 841,000 PEVs sold by 2015 (26%), by far largest PHEV market Over one million PEVs sold in 2015 alone (44% PHEVs).
Strategy Analytics[3] (March 2009)	BEV demand will grow but remain less than 500,000 units a year by 2015 (without business model or technology breakthroughs).
Global Insight[4] (January 2010)	PEVs will comprise nearly 20% of global light duty vehicles in 2030. · 8.6% market share for PHEVs · 9.9% market share for BEVs
PricewaterhouseCoopers[5] (October 2009)	In 2015, PEVs constitute 0.65% of global light vehicle assembly. · Over 500,000 PEVs produced · 100,000-200,000 PHEVs · 300,000-400,000 BEVs
J.D. Power and Associates[6] (October 2010)	1.3 million global BEV sales in 2020 · 742,000 in Europe · 332,000 in China · U.S. and Japan each about 100,000

[1] The Goldman Sachs Group, Inc., July 27, 2010. *Americas: Clean Energy: Energy Storage.*
[2] Pike Research, September 2010. *Plug-In Electric Vehicles.*
[3] Strategy Analytics, March 2009. *Battery Electric Vehicles: Will New Activity Drive Market Out Of Niche?*
[4] IHS Global Insight Group, January 2010. *Battery Electric and Plug-in Hybrid Vehicles: The Definitive Assessment of the Business Case.* Available from: http://www.inrets.fr/fileadmin/recherche/transversal/pfi/PFI_VE/pdf/ElectricVehicleWhitePaper.pdf
[5] PriceWaterhouseCoopers, October 2009. *Adopting electric vehicles: The role of technology and investment.* Available from: http://www.pwc.com/ar/es/publicaciones-por-industria/assets/adopting-electric-vehicles.pdf
[6] J.D. Power and Associates, October 2010. *Drive Green 2020: More Hope Than Reality.*

Findings

Virtually all major vehicle manufacturers and several start-up companies are offering—or are planning to offer soon—a PEV for sale in the U.S. market. PEV offerings have also been announced throughout Europe and Asia. While U.S. automakers are working on PEVs, the U.S. electric vehicle industry lags behind other regions—particularly Asia—in the areas of battery manufacturing, supply chain development, and raw materials production. PEVs may never dominate the mass vehicle market, but it is possible—some experts say likely—that they will capture a significant share (5-15%) of the market over the next 15 to 20 years.

****When the U.S. government established the goal of putting one million PEVs on the road by 2015, the future of the technology and the financial capability of the U.S. auto industry were uncertain. The production intentions of automakers are currently insufficient to meet the 2015 goal, and even the current plans for production volume may not be met.*** *Automakers could ramp up PEV production if consumer demand proves to be larger than expected. However, consumer demand for PEVs is quite uncertain and, barring another global spike in oil prices, may be limited to a minor percentage*

*The portions of this finding in bold are supported by the preceding text, while the content of those portions not in bold will be addressed in subsequent sections.

of new vehicle purchasers (e.g., early technology adopters and relatively affluent urban consumers interested in a "green" commuter car).

Demand-Side Concerns

Although buying a PEV can reduce or eliminate the expense of gasoline, protect the environment, and enhance our national energy security, there are considerable demand-side concerns about the future of PEVs. Buying a new vehicle is a complex, important, and subjective decision, and consumers differ considerably in their reasons for purchasing a new vehicle and what they expect—and fear—about new vehicles. Thus, in order to appreciate the challenge proponents of PEVs face in generating a robust market, it is necessary to grapple with the diverse needs, perceptions, and preferences of all types of retail car purchasers.

Early Adopters

Early adopters of PEVs are those consumers for whom concern for the environment and/or enthusiasm for new technology outweigh the risks, inconveniences, costs, and uncertainty of owning a car powered by emerging technologies. The size of the early adopter population is much debated, and it remains to be seen how large it will be for PEVs.

Even without a complete resolution of many of the BEV-related challenges of recharging infrastructure, battery reliability, and uncertain resale value, Nissan received 20,000 pre-orders for the LEAF in the United States by September 2010 and had to stop taking orders.[83] Given the enthusiasm among early adopters, selling the 10,000 Chevrolet Volts planned for 2011 does not appear to be difficult either.[84]

Although these numbers are impressive, these indicators do not demonstrate that PEVs can achieve mass commercialization, as one cannot assume that the sales will continue at the same rate once the early adopter market is exhausted. The initial LEAF and Volt owners are likely to be classic early adopters, and it would be insightful to compare their characteristics to the initial buyers of the Toyota Prius in the 2000–02 period. In addition, commercial prospects for the Volt have been hampered by the CARB ruling that the Volt was not sufficiently environmentally friendly to warrant single-occupancy access to HOV lanes, and by some reviewers using the word "pricey" (even after federal tax credits) to describe the Volt.[85]

Fleet Buyers

A promising early market for PEVs is corporate and government fleets where a fleet manager is responsible for tracking fuel and other maintenance expenses. If fuel savings can pay for the extra cost of the PEV, these finance-oriented fleet managers may be readily persuaded.[86] A fleet buyer may be particularly intrigued about PEVs if the vehicles can be recharged at central locations and if short and predictable routes do not exceed the electric range of the battery pack. Alternatively, corporate and government buyers of fleets may wish to cultivate a reputation for "green" purchasing behavior, even if the financial case for PEVs is not strong. Thus, commercial success in fleet markets is an important strategy for helping an emerging technology bridge the gap between early adopters and mass retail customers.[87] The promise for electrification of corporate fleets was recently demonstrated by General Electic Corporation's November 2010 announcement of its plans to buy 25,000 PEVs for its fleet by 2015.[88]

Mainstream Consumers

From the perspective of the ordinary car purchaser, the PEVs to be offered over the next several years are likely to be perceived as expensive, risky investments that could cause unexpected inconveniences. In other words, it may not be very easy for dealers to sell PEVs in high volume to average retail customers.[89]

The following sections describe the various hurdles to mainstream consumer acceptance.

Sensitivity to Vehicle Price

Consumers shop for many items on a regular basis, and they know that it often pays to compare the prices of seemingly similar items. Cars are no different. All else being equal, if car A is priced at $28,000 while car B is priced at $25,000, many (but not all) consumers will find a reason not to spend the extra $3,000. There are ample indications of this price sensitivity: the frequency of customer bargaining with dealers, the array of complicated discounts and incentives aimed at persuading buyers that the negotiated price is reasonable, and the elaborate financing schemes—including leasing deals—designed to persuade consumers that a car is affordable.

There is already a well-known consumer resistance to paying $3,000–$5,000 extra for an advanced propulsion system such as a conventional HEV or a diesel engine. Yet proponents of PEVs are asking consumers to contemplate an even larger up-front investment. Given the current cost of producing lithium-ion batteries, the premium for a PEV—especially a BEV—may be in the range of $10,000–$20,000, depending on the vehicle.* Production costs for PEVs may decline substantially in the years ahead due to economies of scale. But, today, the large cost premium of PEVs, if passed on to the consumer, will be resisted by many buyers.

Given this price sensitivity, it should not be surprising that producers of PEVs—following the experience of conventional HEVs—will find their initial marketing successes among relatively high-income and/or wealthy individuals. Once this relatively small pool of wealthy buyers is exhausted, the PEV producers will confront the reality of the cost-conscious retail car buyer.

Insensitivity to Fuel Savings

Although consumers certainly dislike high fuel prices, anticipated prices may not be high enough to induce purchase of a new PEV based on the potential savings in fuel costs. There are many schools of thought regarding drivers' reactions to fuel prices and possible fuel savings.

One view argues that consumer reactions to high fuel prices are not limited to purchasing a new vehicle. Possible consumer responses include reducing discretionary miles of travel; shifting trips from car to another mode (e.g., bus or subway); relocation of work, home, and other activities (to reduce expense of transport); or the most common response, which is simply spending more to maintain existing behavior.[90]

An alternative view is that consumers undervalue the financial benefits of fuel economy compared to what will really happen because consumers have a short time horizon and they may perceive the future benefits to be quite uncertain.[91] The short time horizon, which may be three or four years (rather than the 10–15 year vehicle lifetime), is partly because new vehicles are typically re-sold after three or four years of ownership, and consumers may fear that fuel economy will not command a premium price in the used car market. Consumers may also lack the skills to perform the present-value calculations that supports the investment in fuel economy (Table 4). Even if a consumer appropriately values fuel economy savings, the benefits of these savings will likely be weighed against the consumer's preference for fuel-consuming features such as horsepower, vehicle size, and safety.[92]

The consumer also faces uncertainty in knowing how much money from fuel savings will result from buying a PEV. Future fuel prices, electricity prices, and utility rates are an unknown, and fuel prices have proven to be especially volatile. How a vehicle is driven influences its mileage. Some vehicles don't achieve the mileage in real-world driving that is suggested

*Further discussion of battery costs in the following section, "Supply-Side Concerns," see pp. 36-37.

by official government mileage ratings. In contrast to these unknowns, the upfront price of a PEV can be known with precision.

Regardless of the precise explanation, consumer insensitivity to fuel prices adversely affects commercial prospects for PEVs, which are emblematic of higher vehicle costs in exchange for lower fuel expenditures. Thus, even if the price of fuel rose significantly due to market forces or higher gasoline taxes, the resulting boost in PEV sales may not be as large as some models might predict.

Limited Driving Range

One of the reasons that BEVs failed to survive the market test in the past is that many potential consumers experienced some degree of "range anxiety." The nightmare of an exhausted battery and no nearby recharging station is readily compared to the convenience of today's gasoline refueling stations. A workable recharging arrangement is far more critical for BEVs than for PHEVs (since BEVs have no back-up gasoline engine) but all PEVs need to have a convenient, inexpensive way for batteries to be recharged (or replaced).

Pilot testing suggests that range anxiety can be addressed. In BMW's 2009–11 trial of the all-electric MINI-E, 450 motivated "pioneers" in Los Angeles, New York, and New Jersey leased the vehicle for $850 per month.[93] This rate is more than triple the lease rate for a base model MINI Cooper, but it included a 220-volt home charger—plus coverage of insurance and maintenance—that accomplished full recharging in three to four hours.[94] These users indicated that the vehicle's 100-mile range was adequate to meet their needs, but they preferred home recharging over recharging arrangements at work or in the

Table 4. Payback Period for HEV Premium by Gasoline Price and Miles Driven per Year*

12% Discount Rate

Miles driven per year	*Cost per gallon gasoline*	*Fuel savings per year*	*Payback period (years)*
10000	$2.50	$375	29
12000	$2.50	$450	15
15000	$2.50	$563	10
20000	$2.50	$750	6
Miles driven per year	*Cost per gallon gasoline*	*Fuel savings per year*	*Payback period (years)*
10000	$3.00	$450	15
12000	$3.00	$540	10
15000	$3.00	$675	7
20000	$3.00	$900	5

6% Discount Rate

Miles driven per year	*Cost per gallon gasoline*	*Fuel savings per year*	*Payback period (years)*
10000	$2.50	$375	12
12000	$2.50	$450	9
15000	$2.50	$563	7
20000	$2.50	$750	5
Miles driven per year	*Cost per gallon gasoline*	*Fuel savings per year*	*Payback period (years)*
10000	$3.00	$450	9
12000	$3.00	$540	7
15000	$3.00	$675	6
20000	$3.00	$900	4

*Assumptions: HEV compared to conventional vehicle has 15 mpg increase and $3000 incremental vehicle cost.

community.[95] The reported negatives were the lack of a rear seat and a lack of trunk space, attributes that are salient in the highly competitive new-car market.[96]

Range anxiety may be exacerbated if PEVs do not achieve the range that manufacturers claim at the point of sale. Many manufacturers use EPA Federal Test Procedure results as the advertised range of the vehicle, but, in practice, these vehicles are not likely to achieve the range that was possible under test conditions. During the test procedure, batteries begin at their maximum charge and are run until the car stops.[97] This driving pattern is neither good for the battery nor how a driver is likely to operate his or her vehicle.[98] Some speculate that a realistic average range for a PEV is approximately 70% of the range on the EPA test procedure.[99] EPA has recently released all-electric range estimates for the Nissan LEAF (73 miles) and the Chevrolet Volt (35 miles) that are lower than the previously released results, apparently better reflecting real-world driving outcomes.[100]

Inconvenience and Cost of Recharging

Most utilities and automakers agree that the primary focus for PEV recharging should be at residences with workplace recharging a second priority and community recharging only deployed where it is likely to be widely used. This model of recharging is a practical reflection of where vehicles are most often parked during the 24-hour day.

In order to recharge their vehicle at home, consumers will need to have sufficient breaking capacity (the highest level of electrical current a fuse can accept without breaking), an electrical connection in the garage, and a charger with the appropriate voltage (see Table 5). Two levels of recharging are currently standardized in the United States with a third high-speed standard under consideration. Level 1 recharging is 120 VAC, up to 15 amps and 1.8 kW power level, which is similar to many home appliances today.[101] Level 1 recharging is appropriate for PHEVs, though it may take 8–20 hours to fully charge the vehicle at that level. Level 2 recharging is a 240 VAC standard, up to 80 amp and 19kW, which will fully charge a PEV in three to eight hours.[102] Some proponents of PHEVs hope that owners will be satisfied with Level 1 recharging, but PHEV owners may insist on Level 2 recharging (or better).

The costs of residential recharging systems vary depending on availability of sufficient breaking capacity in the home, distance from the meter to the vehicle, the speed of recharging required, and the availability of a garage or carport. Costs range from around $1,500 to $2,500 for a residential installation of Level 2 recharging.[103]

A key question becomes who will incur the cost of recharging. Once a retail consumer realizes that they may have to pay approximately $2,000 for home-charging capability in addition to a $10,000 premium for the vehicle (relative to a non-PEV of similar size), enthusiasm for the PEV purchase may wane. Used vehicle purchasers must also make this $2,000 investment, a reality that will depress resale values. Federal tax credits to offset the costs of recharging infrastructure were available for up to $2,000 for residences in 2010. Congress recently renewed these credits for 2011 but lowered them to

Table 5: Types of Recharging Infrastructure

Level	*Volts/Amps*	*Electricity Delivered*	*Time to Charge 24kWh Battery to 80%*	*Available for At-Home Charging?*
Level 1	120/15	~1.8 kW	20 hours	Yes
Level 2	240/80	Up to 19.2 kW	7 hours	Yes
DC-DC	480	50 kW	30 minutes	No

*Sources for this table include: *Answers: Charging.* Nissanusa.com. Accessed January 15, 2010. Available from: http://www.nissanusa.com/leaf-electric-car/faq/list/charging#/leaf-electric-car/faq/list/charging
AND *Charging Equipment for Plug-in Hybrid and All-Electric Vehicles. Alternative Fuels Data Center*, Department of Energy. Last updated Sept 8, 2010. Available from: http://www.afdc.energy.gov/afdc/vehicles/electric_charging_equipment.html

the pre-2010 level of $1,000. Even if the credits are again renewed temporarily, they are unlikely to last beyond the "early adopter" phase of commercialization.

Nor will a $2,000 investment be sufficient for many retail car buyers. Not everyone has a garage or parking place with ready access to an outlet suitable for recharging. In fact, many consumers that might otherwise find the LEAF appealing—urban dwellers with short commutes—are likely to lack recharging access at their home.

The communities that were included in Nissan's 2009 plans for the LEAF roll-out[104] vary widely in their likelihood of having the potential for home recharging. Only 11.9% of housing structures in Boston are single-family detached homes, while Sonoma County has 68.8% of its housing as single-family detached homes (see Figure 2).[105] All LEAF roll-out communities except Sonoma County have a lower percentage of single-family detached homes than the national average of 64%. A higher percentage of one-unit detached homes indicates, unsurprisingly, a higher percentage of garages or carports: 82% of single-family homes have garages or carports, compared with about 25% for structures with 10–49 housing units (i.e., apartment complexes). For retail car buyers who share a parking area with other owners or renters, the prospect of having to negotiate a special parking place for their PEV will further dampen enthusiasm for a PEV purchase.

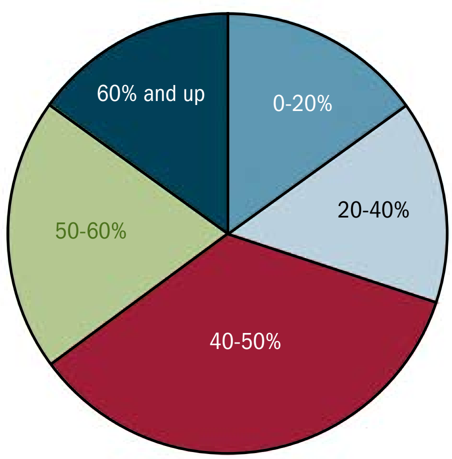
Instead of leaving home recharging responsibilities for car buyers to arrange, alternative business models for public recharging have been suggested. Two competing models are the battery-switching approach and quick-charging kiosks that leave batteries in place.

In the battery-switch model, the owner of a PEV would not own the battery needed to run the car. Instead, the consumer would sign up for a battery-switching plan at the time he purchased the vehicle and would be billed for the ability to replace the depleted battery at nearby stations.[106] Better Place, the most prominent company in the battery-switching arena, is working with several countries (e.g., Israel and Denmark) to establish networks of switching stations and recently signed an agreement to bring an electric taxi program to the San Francisco Bay Area.[107] This business model improves the speed of a non-residential recharge, reduces the consumer's financial risk of owning an expensive battery pack, and eliminates consumer anxiety surrounding resale of the battery. From a load-management perspective, it may be easier for power companies to persuade a limited number of businesses to recharge their inventory of batteries in off-peak hours than to persuade individual motorists to behave responsibly.

Although it is an intriguing idea, the business model for battery-switching faces formidable obstacles. These new businesses would have very high capital costs (for inventory) and would require all automakers to constrain the design of their PEVs to facilitate easy removal and replacement of the battery pack.[108] If new battery chemistries emerge, the businesses would have to stock many types of batteries, which would add to the already-high capital costs.

Figure 2: LEAF Roll-Out Cities Percentage of Detached Housing Units

Boston	11.9%
Washington, DC	12.7%
San Francisco	16.9%
Bridgeport	25.2%
Orlando	36.4%
Los Angeles	39.8%
Dallas	45.6%
Houston	45.8%
San Diego	45.8%
Austin	47.4%
Seattle	47.5%
Raleigh	47.8%
Denver	48.8%
Tucson	51.8%
Nashville	54.8%
Sacramento	58.7%
Portland	59.7%
Phoenix	60.5%
Indianapolis	60.9%
Sonoma County	68.8%



Data adapted from the U.S. Census' 2006-2008 American Community Survey 3-Year Estimates. Bridgeport, Denver, Dallas, Nashville, Raleigh, and Porltand are cities chosen as examples within the following larger areas that Nissan identified as a roll-out target: CT/NE Utilities, Colorado, Dallas/Ft. Worth, TN/TVA/ORNL, Progress Energy/Advanced Energy, and Oregon/PGE. Note that data are for city limits; the surrounding metropolitan areas were not included.

The quick-charge model would leave battery ownership in the hands of car owners and allow them to recharge in a short period of time while away from home. A proposed system from AeroVironment, Inc. utilizes kiosks that look similar to gasoline pumps but instead deliver a charge of 125-250 kW.[109] The company claims these stations can recharge a vehicle battery in minutes.[110] Alternatively, motorists might recharge at kiosks strategically placed at desirable locations, such as shopping malls. Community recharging can also be used to "top off" the vehicle battery rather than as a source for a full charge after a battery is depleted.[111]

There are also drawbacks to this approach. There may be a tradeoff between the speed of the charge provided on a regular basis and the lifespan of the battery.[112] State public utility commissions and other regulatory bodies need to resolve how to regulate community recharging stations.[113] Quick-charging stations will be very expensive ($110,000–$160,000 per station),[114] and businesses investing in these stations would likely pass these costs on to consumers. Gasoline stations are poor locations for quick-charging because motorists do not want to spend time there. Alternatively, quick-charging kiosks may be installed at designated recharging facilities or dual-purpose locations such as parking garages near shopping malls, either for a fee or as a free amenity to attract customers.

Some recharging points may be publicly provided. The state of Washington has passed legislation requiring the installation of recharging points at all rest stops and state parking facilities by 2015.* While most currently installed community recharging stations are Level 2 chargers, DC fast chargers are beginning to crop up. The town of Vacaville, Calif., recently became the first city in the United States to install a DC fast charger.[115] With U.S. Department of Energy (DOE) funding, Ecotality and Nissan are partnering to bring 10,950 Level 2 chargers and 260 DC fast chargers to Arizona, Tennessee, California, Oregon, and Washington.[116] While some early governmental investments in recharging infrastructure may be appropriate in demonstration communities, the PEV industry cannot thrive without a viable, private-sector model for recharging.

In summary, a fundamental challenge for the future of the PEV industry is to overcome "range anxiety" on the part of potential PEV purchasers. For all PEV purchasers, the knowledge that public recharging is available may decrease this anxiety even if their use of public recharging is minimal. For PHEVs, the primary challenge is to accomplish home recharging at minor expense, at least for those who have a garage or a parking spot near an appropriate outlet. Some PHEV owners may also want recharging available at work and in some public places. For BEVs, the need for recharging in the community and on highways—preferably fast charging—is essential for mass commercialization. As of late 2009, there were fewer than 1,000 recharging stations in the United States.[117] By way of comparison, there are 170,000 gasoline refueling stations. A viable business model for recharging is not yet apparent.[118]

Ease of PEV Purchase and Prompt Use

When consumers buy or lease a new car, they want to use it promptly. BMW's experience with the pilot test of the MINI-E revealed that many communities are ill-prepared to facilitate purchase and use of PEVs. Before any lessee could drive the MINI-E, the 220-volt charger had to be installed in his or her garage.[119] That installation requires a site inspection of the lessee's home with a vendor and a subcontractor to handle the new fuse box panel. About a quarter of the home installations ran into unexpected costs for upgrades. Those in condominiums or apartments often needed to renegotiate new parking places to make sure the electric meter was close enough to the lessee's assigned space.

BMW projected charger installation within 30 days of the car's delivery date.[120] While it took only a few days in California, it could take as many as three weeks in some areas to obtain the official approvals and the needed electrical hookups.[121] Other automakers' experiences indicate similar problems nationwide: Until Nissan began working with city officials in Raleigh, N.C., it could take a week to get a permit and another week for an inspection and installation.[122] All of these issues are resolvable, but PEV sales to consumers will be slow until they are resolved.

**Washington Incentives and Laws*, Alternative Fuels and Advanced Vehicles Data Center. Department of Energy. Last updated March 2010. Available from: http://www.afdc.energy.gov/afdc/laws/state_summary/WA

Perceived Reliability/Durability

When the Prius and Insight were first introduced, one of the barriers to sales was a perception that the batteries in these conventional hybrids would lack reliability and durability. In fact, the nickel batteries used in conventional hybrid vehicles have a strong record of reliability, but it has taken years for this record to build confidence in the car-buying public. Some surveys continue to show that hybrids trail conventional vehicles in perceived reliability.

PEVs will confront a similar challenge, and the necessary shift from nickel to lithium-ion batteries for PEVs means that the reassuring experience with the Prius is not necessarily applicable to PEVs. For example, when Toyota offers the plug-in version of the Prius and shifts from nickel to lithium-ion batteries, customer confidence in lithium-ion batteries will have to be reestablished.

A closely related concern is that consumers want a vehicle that can be serviced promptly, competently, and inexpensively. Yet many car repair shops and dealers have no experience with PEVs, and it is not yet clear how quickly they will learn new tricks of the trade. Many consumers think carefully about servicing issues before they purchase or lease a vehicle.

Consequently, Nissan, the largest vehicle manufacturer with a big stake in the future of BEVs, is now undertaking a major effort to train its service personnel at Nissan dealerships, making sure they are ready for the unique service demands that will accompany the rollout of the LEAF.[123] In 2010, Nissan began bringing each of its 1,000 dealers through a four-day LEAF training session at its new center outside San Francisco. The LEAF's battery module—a large, flat component that weighs 600 pounds—is composed of 48 modules, and each one may need to be serviced. Dealers must have a forklift on their premises to move the batteries around as well as insulated hand tools for electrical safety.

Competition from Alternative Technologies

While PEVs are a prominent innovation, consumers interested in using less petroleum to drive will have a variety of technologies to choose from in the years to come (see Table 6). New competing technologies are also making some progress in bringing down costs, thereby reducing their own barriers to commercialization. Refinements to gasoline and diesel engines, including conventional hybrid-electric systems, are improving their fuel efficiency. As a result, the requirements for any PEV to enter the market are continuously becoming more demanding.[124]

Perceived Resale Value

One of the considerations involved in a new vehicle purchase decision is the buyer's estimation of the car's resale value. PEVs are perceived as a brand-new technology, so their resale value has not yet been tested. Additionally, unless a quick-charging station is nearby, used-car buyers would need to have recharging infrastructure installed in their home and may be unable to use a tax credit to subsidize this expense. Used-car buyers are also likely to be concerned about purchasing an expensive battery that has already deteriorated somewhat and may need to be replaced. Any of these factors that suppress demand for PEVs in the used-car market will become known in the new-car market, giving new-car buyers more reason to be cautious about paying a premium price for a PEV.

If early experience with PEVs is positive and if another global spike in oil prices pushes fuel prices over $4 per gallon, the value of PEVs in the used-car market could grow rapidly.

Table 6: Developmental Stages of Various Engine Technologies

Technology	*Development Stage*
Internal Combustion Engine Vehicles	Mature
Conventional Hybrid Electric Vehicles	Approaching maturity
Hydrogen Fuel Cell Vehicles	Demonstration phase
E85* Vehicles	Mature, except for cellulosic ethanol
Compressed Natural Gas Vehicles	Early adopter phase
Liquified Natural Gas Vehicles	Early adopter phase

*A blend of 85% ethanol and 15% gasoline.

This was the experience with conventional HEVs such as the Prius. Their resale value has fluctuated considerably based on overall market conditions.[125]

Safety

Lithium-ion batteries are associated with potential safety risks: They can potentially dispense the energy they store too rapidly, which has resulted in a few incidents of consumer electronics spontaneously bursting into flames.[126] If real-world safety problems surface with the first generation of PEVs, the resulting negative impact on the technology's reputation could be severe. One of the reasons that Toyota has delayed the company's transition from nickel to lithium-ion batteries is a concern that lithium-ion batteries will have safety problems under unusual yet plausible conditions of use.[127]

The damage that safety troubles inflict on an automaker's (or supplier's) reputation was demonstrated in early 2010 when Toyota issued a widespread recall due to (allegedly) faulty gas pedals. Toyota quickly lost its top rank for both consumer loyalty and perceived quality among survey respondents.[128] Sales declined 9% during the month of the recall, while competitors Ford and GM saw their sales jump 43% and 12%, respectively.[129] And Toyota has incurred some lasting reputational damage from the incident, even though the recent investigations by federal agencies found no design defect and instead suggested that the incidents were caused primarily by misuse of the pedal by drivers.[130]

Findings

When the U.S. government established the goal of putting one million PEVs on the road by 2015, the future of the technology and the financial capability of the U.S. auto industry were uncertain. The production intentions of automakers are currently insufficient to meet the 2015 goal, and even the current plans for production volume may not be met.* ***Automakers could ramp up PEV production if consumer demand proves to be larger than expected. However, consumer demand for PEVs is quite uncertain and, barring another global spike in oil prices, may be limited to a minor percentage of new vehicle purchasers (e.g., early technology adopters and relatively affluent urban consumers interested in a "green" commuter car).*

Four market factors, each of which can be influenced by public policy, present the greatest potential for altering the competitive position of PEVs in the vehicle market: (1) energy prices; (2) battery characteristics (safety, reliability, and production costs); (3) the availability of convenient and affordable recharging infrastructure; and (4) the pace of progress with PEVs compared to competing technologies, such as refinements to the internal combustion engine, conventional hybrids, advanced biofuels, natural gas vehicles, and fuel cell vehicles.

One key reason that mass commercialization of PEVs may proceed slowly over the next decade is that mainstream retail purchasers of new vehicles differ from the relatively small number of enthusiastic "early adopters." Mainstream car buyers are careful about investing in new technologies that are not fully understood. There are a variety of uncertainties about exactly how much money will be saved by PEVs (savings depend on uncertain forecasts of fuel and electricity prices), how reliable and safe the batteries will be, how convenient and costly it will be to recharge a PEV, how easy it will be to have the vehicle serviced, and how difficult it will be to resell the vehicle. Although proponents of PEVs are making progress in resolving these uncertainties, consumers will ask many questions before purchasing a PEV and will wait to hear from others who choose to experiment with a PEV.

Initial consumer experiences with PEVs—their real-world driving range, cost, safety, reliability, and ease of recharging and resale—will exert a significant influence over mainstream consumers' perceptions of PEVs. If customer expectations are inflated (by automakers, dealers, power companies, environmental groups and/or government officials) relative to

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*The portions of this finding in bold are supported by the preceding text, while the content of those portions not in bold were addressed in subsequent sections.

what is actually experienced, the reputational damage to the technology could be significant and possibly irreparable. News stories are already describing the "hype" associated with the campaign for PEVs.

Both PHEVs and BEVs are designed with the intention of using residential recharging as the primary refueling method, but BEVs also depend on the emergence of some recharging stations in the community. The obstacles to residential recharging are less challenging than community recharging, but more imperative to overcome. The biggest barriers to residential recharging are faced by those consumers who would otherwise find PEVs most attractive: urban dwellers with short commutes who often lack garages or convenient access to an electrical outlet. Additionally, most municipal regulations and permitting processes are not yet designed with PEVs in mind and present a bureaucratic obstacle to the timely and efficient installation of residential recharging units. Workplace recharging will also be helpful and is already sponsored by some employers, but will occur less frequently than residential recharging. Retail outlets may have commercial incentives to install recharging facilities if sufficient demand develops, but the short-term need for community recharging is limited, installation remains expensive, and bureaucratic and technological obstacles persist.

Supply-Side Concerns

For vehicle manufacturers, suppliers of components, and venture capitalists intrigued by the future of PEVs, a central question is whether to test the waters as a first mover or sit back and respond later. It is one thing to offer a PEV, perhaps in limited volume to satisfy CARB's requirements for ZEVs; it is quite another to do so on a profitable, mass-production basis in a global industry that is quite competitive.

While most of the attention is properly focused on the need for new battery capabilities, electrification will require more than a dozen new systems that are not needed for gasoline-powered vehicles (e.g., special gear boxes for the higher electric RPMs, electric power steering, electric water pumps that can circulate coolant for the traction motor, etc.). A new supply chain in the manufacturing sector will be necessary to support a robust PEV industry.[131] Thus, it is critical to consider the supplier's perspective, both the supplier of the vehicle and the many suppliers of components throughout the vehicle supply chain.

Battery Costs

In May 2006, DOE hosted more than 120 experts from academia, government, national laboratories, and the automotive and electric utility industries to discuss PHEV technology and economics. The consensus was that the primary impediment is cost, and limitations of battery technology are a potential showstopper.[132]

Since cost information is generally proprietary, only estimates of battery costs are available. For the PEVs currently being sold in the U.S. market, the unit cost estimates (expressed in units of kilowatts per hour [kWh]), are $680/kWh for the Tesla Roadster,[133] $500–600/kW h for the Chevrolet Volt,[134] and $375–750/kWh[135] for the Nissan LEAF. The United States Advanced Battery Consortium has set cost-reduction targets with a mid-term goal of $250/kWh and a long-term goal of $100/kWh.[136] A 2009 report from the National Research Council (NRC) predicted that these goals may not be realized for many decades. Assuming no technological breakthroughs, the NRC's committee projected a lithium-ion battery pack cost of $500/kWh in 2030 (in today's dollars). However, some manufacturers may already have met or exceeded this figure. Nissan has publicly stated that their battery cost per kWh has dropped 50% in the last four years.[137]

The conclusions of the NRC report were met with dispute from organizations such as the Electrification Coalition that believe the committee overestimated current battery costs and failed to account for the economies of scale that would be achieved at larger production volumes.[138] Several other estimates of battery cost reductions support the Electrification Coalition's claim that battery costs will be reduced further than the NAS report anticipates. A 2009 report from *McKinsey Quarterly* projected that battery costs could be reduced to $420/kWh by 2015 in an optimistic scenario.[139] A 2010 survey of experts on the subject found that there was a 66% chance that a battery cost below $200/kWh could be achieved, assuming sufficient government R&D funding.[140]

The lithium-ion battery has been the primary technology for PEV applications because it optimizes combined power and energy density, especially when compared to the nickel-metal hydride chemistry that powers traditional hybrids. However, the lithium-ion battery is limited by concerns about safety, how long the battery will last before it must be replaced, and how quickly the battery will deplete after each successive recharge.

Alternate lithium-based battery technologies hold promise for vehicle applications. Stimulus funds through the DOE have recently invested in 20 advanced research projects that could reduce battery costs as much as 90%, if successful.[141] These projects include semi-solid and "all-electron" batteries.[142] In addition, researchers at Argonne National Laboratories are studying lithium-air batteries, which could substantially increase energy density.[143]

In summary, the unit costs of lithium-ion battery packs for automotive applications appear to have declined significantly, but the pace of further decline is far from certain. Refinements of the lithium-ion technology may be sufficient to commercialize PHEVs, but an entirely new energy-storage capability may be necessary for BEVs given consumer demands for driving range and affordability. The commercial experience of Nissan with the LEAF will provide critical information on the near-term viability of BEVs. Alternative battery chemistries are certainly worth significant R&D support.

Battery Production Capacity

Korea, Japan, and China currently supply 95% of the world's advanced batteries with Sanyo, Samsung, and LG Chem leading the industry.[144] If consumer demand for PEVs grows more rapidly than expected in the United States or Asia, the PEV industry, aided by sympathetic governments, seems likely to respond and meet the demand. Large battery plants are under construction in the United States, Japan, South Korea, and China, where government and industry are convinced that HEVs—and possibly PEVs—will capture increasing shares of the global vehicle market. The European industry appears to be more fractious and less nimble, and both the EU and the German government continue to resist the French and Spanish calls for subsidies to support near-term commercialization of PEVs.*

The United States played a leading role in the early development of lithium battery technology. In the 1980s, researchers at the University of Texas at Austin developed the cathode materials necessary for a rechargeable lithium battery.[145] In 1992, the United States Advanced Battery Consortium—formed by the Big Three automakers (Ford, GM, and Chrysler), the Electric Power Research Institute, and DOE—awarded contracts for R&D, which included funds for lithium-polymer development and lithium-sulfide research.[146] Despite early breakthroughs, U.S. battery manufacturers did not aggressively pursue lithium-ion batteries, due in part to estimates of low automotive demand for batteries and low profit margins relative to other battery applications.[147] While the United States declined to develop a domestic lithium battery industry for vehicle applications, the industry thrived elsewhere.

Japan was able to move ahead in this market due to its industrial-policy emphasis on growth in long-term market share (rather than a focus on near-term profits) and its pattern of fostering close inter-industry partnerships (e.g., the relationships between the Japanese battery industry and consumer electronic product designers and producers).[148] Through aggressive implementation of this industrial policy, Japan has emerged as the world's leading producer of advanced batteries.[149]

Panasonic, maker of about 80% of the world's nickel-hydride batteries used in vehicles, is now a key player in lithium-ion batteries due to its purchase of Sanyo Electric Company, the world leader in lithium-ion technology for cell phones and computers.[150] In 2009, Sanyo announced a $1 billion plan to rapidly expand lithium-ion battery production, with two new plants already underway.[151] A complication is that Panasonic, though it has done business with GM, Chrysler and Honda,

*Further discussion of EU PEV policy follows in the section "An International Perspective on Policy," see pp. 53-56.

has strong ties with Toyota.[152] Toyota's joint venture with Sanyo does not share technology with other vehicle manufacturers and suppliers.[153]

Beginning in 2008, Nissan teamed with NEC Corporation of Japan on building a new $115 million facility to make 65,000 battery packs per year by 2011.[154] Nissan and NEC have a proprietary battery technology that produces twice the power output of typical batteries and with less risk of safety problems due to overheating.[155] The Nissan–Renault relationship is also helping Renault take a leadership position in the fledgling European PEV industry.

Japan's global leadership position is not assured in the future. South Korea and China are emerging as serious Asian competitors.

South Korea recently announced a national investment equivalent to $12.5 billion, the "Battery 2020 Project," to become the dominant battery producer in the next 10 years.[156] This is a boost to Samsung SDI and LG Chem, South Korean-based global companies with strong positions in lithium-ion batteries. In fact, a subsidiary of LG Chem, Compact Power, Inc. (Troy, Mich.) will produce PEV batteries for both GM and Ford vehicles.[157] In 2009, Robert Bosch GmbH (Stuttgart, Germany), the world's largest automotive supplier, teamed with Samsung SDI to break into the battery business.[158] The partnership later acquired the battery producer Cobasys (Detroit).[159] Beginning in 2013, a new Samsung plant in South Korea will supply batteries for both HEVs and PEVs.[160]

China has also released a national plan to become a global leader in battery technology for vehicle applications. China's competitive advantages (inexpensive labor, raw material access, and favorable government incentives)[161] have allowed the country's global market share in batteries (of all types) to grow from 11% in 2002 to 25% in 2009.[162] The lithium reserves in the country are the fourth-highest worldwide.[163] Chinese universities are involved in spurring the technology's development: Tsinghua University focuses its research efforts on PEVs, HEVs, and fuel cell vehicles and their battery applications, while the School of Engineering at Tongji University integrates batteries and vehicles for research, testing, and evaluation.[164] The combined force of these factors led to 120 companies producing lithium-ion batteries in China as of 2008.[165]

A variety of U.S.-based and foreign companies play a role in the small but rapidly developing U.S. battery industry. Boston Power (Westborough, Mass.) will supply lithium-ion batteries for Saab's first electric car. The French battery-maker Saft, in partnership with Johnson Controls (Milwaukee), is expanding lithium-ion battery production for automotive applications and has relationships with GM, Daimler, and BMW. A123 (Watertown, Mass.), a start-up with strong support from General Electric Corporation and the venture capital community, has recently signed battery supply contracts for Navistar's all-electric urban delivery truck and a Chinese automaker's all-electric subcompact sedan (SAIC Motor). EnerDel (Indianapolis), arguably the pioneer of lithium-ion battery production in the United States, will supply Volvo for the electric version of the Volvo C30, building on its smaller relationships with TH!NK Global (Norway) and Fisker Automotive.[166] KD Advanced Battery Group—a joint venture of Dow Chemical Company, Kokam America, and Townsend Ventures—will soon be a supplier of lithium-ion batteries to Smith Electric Vehicles for its all-electric trucks.

The Obama administration, the U.S. Congress, the United Auto Workers, and the Big Three do not wish to become dependent on Asian battery manufacturers. In response to concerns that many of the American dollars spent on PEVs would be sent overseas due to an inadequate domestic battery industry, Congress allocated $2.4 billion in PEV stimulus funding, including grants to nine battery manufacturers.[167] Due to these stimulus investments, the United States' share of global production capacity for advanced batteries is projected to rise from 2% in 2010 to 40% in 2015.[168] But the alignment of U.S. battery production capability with uncertain consumer demand is a tricky matter.

Worldwide production capability is predicted to be 1,500,000 by 2015.[169] Disagreement arises over how this number compares to future demand for batteries. Total Battery Consulting believes that this production level will create "overcapacity by 2013."[170] Pike Research and Lux Research believe there could be a lithium-ion battery glut by 2012.[171] However, battery manufacturer EnerDel thinks that battery production capacity is a main limiting factor for growth in PEV sales and that demand is not a problem for battery manufacturers.[172] Consulting firm PRTM does not predict any significant overcapacities.[173]

Access to Raw Materials

If the PEV industry grows, the competition for access to vital raw materials will intensify. The need for lithium is obvious, but a variety of rare-earth metals also play key roles: dysprosium is used in electric motors, lanthanides (formed from lanthanum) are used for magnets in motor generators, and neodymium is used in high-end magnets.[174]

Relatively unknown in the late 1990s, lithium batteries are now ubiquitous in portable electronic devices. The battery industry comprises about 23% of present lithium demand (see Table 7). By way of comparison, HEVs and PEVs are currently marginal contributors to global demand and are expected to remain below 2% of the lithium battery market in 2012.[175] One forecast calls for sustained long-term growth due to the expected demand for vehicle electrification, resulting in a $100 billion lithium-ion battery market (roughly 14 times the 2009 size) by 2030.[176]

Table 7: Global End-Use Lithium Uses by Market Share

End-use Market	*Market Share*
Ceramics and glass	31%
Batteries	23%
Lubricating greases	10%
Air treatment	5%
Continuous casting	4%
Primary aluminum production	3%
Other uses	24%

Source: U.S. Geological Survey, *Mineral Commodity Summaries 2010*.

Global lithium resources have been approximated at 25.5 million tons, of which 2.5 million tons are in the United States.[177] The majority rests in Bolivia and Chile, with 9 million metric tons and over 7.5 million metric tons, respectively. The majority of "recoverable" lithium reserves (i.e., the resource base that is economically viable to extract or produce) rests in Bolivia and Chile. The third-largest holder of recoverable lithium reserves is Argentina, but it has less than 11 percent of Chile's total. From 2005 to 2008, 63% of U.S. lithium imports came from Chile and 35% from Argentina.

Production of lithium is currently concentrated in Chile (39.3%), China (13.3%), Australia (11.0%), Russia (10.8%), Argentina (9.8%), and the United States (8.4%). Sixty mining companies have lithium feasibility studies underway and the four largest lithium producers are expanding their operations in Argentina, Serbia, and Nevada.[178] The world's biggest supplier of lithium is Sociedad Quimica y Minera de Chile SA, which accounts for 30% of the global market.[179] U.S.-based Chemtall and FMC Lithium together supply 50% of the world's lithium, but, with the exception of Chemtall's use of lithium from Silver Lake, NV, the lithium they provide is sourced from Chile and Argentina.[180]

From a purely numerical perspective, there is little cause for worry about a scarce supply of lithium reserves in the near future. At present production levels, reserves will satisfy automotive battery demand until around 2025, even under an aggressive growth scenario.[181] However, the concentration of lithium in South America raises concerns about political instability that could shrink U.S. access to lithium. Several high-level politicians, including President Morales of Bolivia, have openly discussed nationalizing lithium deposits due to the crucial role lithium plays in the future of the PEV industry.[182] A similar concern relates to cobalt, another cathode raw material: 30% of the world's supply lies in the Democratic Republic of the Congo.[183]

One option for reducing U.S. reliance on lithium imports is recycling, which would lessen the demand for newly mined lithium. The current state of lithium reserves and the small amount of lithium being used today have not warranted significant investments in the costly process of lithium recycling. DOE recently provided California's Toxco with grant funding to build the United States' first lithium recycling facility.[184]

Although domestic lithium recycling could reduce U.S. dependence on lithium imports and the U.S.'s vulnerability to sudden drops in supply, an alternative strategy in the face of a shrinking lithium supply is the use of substitutes. According to the U.S. Geological Survey, substitutes for lithium-ion battery applications include magnesium, mercury, calcium, and zinc as anode material, though these substitutes are all heavier than lithium.[185]

Access to a variety of rare earth materials may prove to be more challenging than access to lithium. One forecast concluded that global demand for rare-earth metals will exceed supply within four years, primarily due to the growing market for HEVs and PEVs.[186]

From a business perspective, arrangements that do not create dependence on foreign countries will become increasingly attractive. The United States, despite having approximately 13% of the world's rare earth metals reserve, has 100% net import reliance for the material.[187] About 90% of these imports to the United States originate in China.[188] The dangers of dependence became clear in the summer of 2010 when China announced it would cut exports of rare earth metals by 40%, citing national security and environmental concerns.[189]

The price of raw materials is currently a small fraction of the cost of a PEV (e.g., lithium currently accounts for about 5% of the cost of large-format car battery), but input prices can fluctuate rapidly.[190] The price of lithium has more than tripled from 1999 to 2010.[191] The price of rare earth metals has gone up dramatically in the last eight years (see Figure 3). In 2010 alone, the per kilogram price of neodymium—which is sourced predominantly from China—doubled.[192] As of mid-2010, Toyota was the only major vehicle manufacturer to have signed corporate arrangements that secure rights to rare earth elements in Argentina, Vietnam, and Canada.[193]

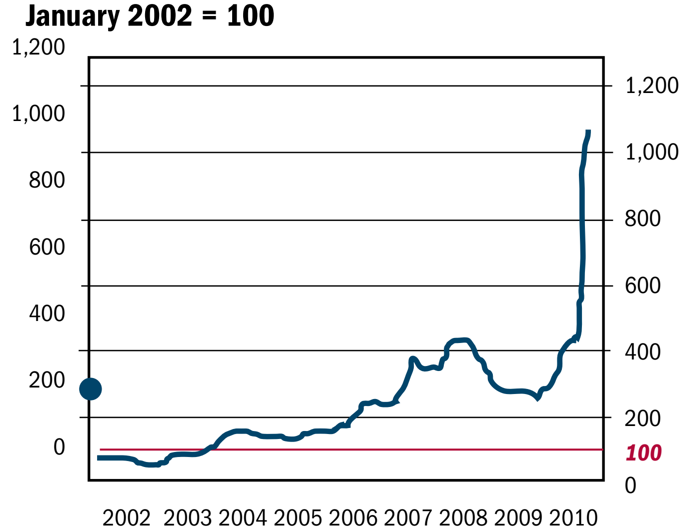
Supply of Other Inputs and Components

Concerns about the supply of battery packs and raw materials are replicated for the many other components that go into making PEVs. As a result, the recent federal stimulus package included $2.4 billion for the supply chain, beyond the grants for battery pack assembly.[194] In addition to the nine grants to battery-makers, 11 grants were awarded to battery component manufacturers and 10 to electric drive component manufacturers.[195]

The United States' lithium-ion battery industry is currently focused primarily on battery pack assembly and mostly imports battery cells, with only EnerDel manufacturing the cells domestically.[196] In cell components, the U.S. industry lags behind on cathode and anode production.

The United States does have a hand in the other two components needed for cell production: North Carolina's Celgard holds 20–30% of the global market share for separators, and the Ohio firm Novolyte is a major supplier of electrolytes. Some researchers believe that venture start-ups will begin to emerge in the U.S. battery component industry in response to the expansion of domestic battery production. In addition, A123, EnerDel, JCI-Saft, and Compact Power are looking at ways to vertically integrate, possibly adding cell production capacity with assistance from DOE.

Figure 3: Rarity Value – Rare-Earths Price Index* January 2002 = 100



* Composite of ten metals

Source: "Rare Earths: Digging In." September 2, 2010. *The Economist.* Available from: http://www.economist.com/node/16944034. Original data from Kaiser Bottom-Fish.

Coordination with Electric Utilities

Large-scale commercialization of PEVs may present electric utilities with significant business opportunity as well as new load management challenges.

Load Effects. Most regional electric distribution systems have excess capacity available for dispatch in the event that the extra electricity is needed for peak loads or increased demand. One of the most important considerations for PEVs is whether there is enough excess capacity to accommodate recharging needs in the short run and how PEV recharging will affect electric loads in both the short and long run.

Many PEV owners are expected to charge their vehicles overnight when the power system commonly operates at below 50% capacity and when electricity is the least expensive to generate. Off-peak power appears to be adequate to handle a large number of PEVs. The Pacific Northwest National Laboratory concluded that sufficient excess capacity exists to charge approximately 73% of the nation's light-duty vehicle fleet or 84% of personal automobiles, pickup trucks, or sports utility vehicles between the hours of 6 p.m. and 6 a.m.[197] These percentage values, however, vary by region.

Existing technologies and electric reliability capabilities—including load control and appliance timers—are adequate to avoid coincident peak loads in the short run. Over the long run, the application of new, emerging smart grid technologies will help manage the PEV-induced charging loads more efficiently and optimize the excess generation capacity while also using intermittent renewable solar and wind energy. It may be useful to implement some smart grid technologies at the same time that PEVs are deployed in demonstration communities.

Although the overall transmission and distribution system is adequate for large-scale PEV deployment, reliability problems due to system overload could occur on a local basis. Statistical analysis of electric distribution systems has shown that spatial diversity of PEV penetration reduces the risk of overloading the primary distribution system. But, as the analysis moves closer to the customer, the risk of overloading local service transformers increases.[198] At this local or neighborhood level, there is increased probability of vehicle clustering. Most utilities routinely plan the size of distribution systems for load growth and peak loads. But utilities in regions with high PEV penetrations or older infrastructure may need to install heavy-duty wires, upgrade local transformers, or invest in smart grid technology to prepare for the strain that PEVs could cause.[199]

The energy demands of a PEV are roughly equivalent to adding a new small house onto the neighborhood grid.[200] Localized transformer overloading can occur at low PEV penetrations if the existing infrastructure is already heavily loaded or subjected to "clustering" of PEVs in specific neighborhoods. Given the role of neighborhood effects on new vehicle sales, such clustering should be expected. One study finds, however, that new generation peaks can be avoided (even at high levels of PEV penetration [9%]) by using advanced meters to stagger residential recharging times.[201] In an effort to address concerns about grid overload, the Electric Power Research Institute has developed an analytical framework for utilities to use in determining the effect of PEVs in their distribution operation and is also working with utilities to conduct analyses to locate infrastructure requiring upgrades.[202]

PEV Effects on Electricity Rates. PEVs are seen by some as a potential new load source, when used in a "vehicle-to-grid" (V2G) capacity. The premise behind the V2G concept is that PEVs will charge during nighttime hours, and then dispatch some electricity back to the grid during peak daytime hours.[203] Due to the expected timing and flexible nature of PEV-provided load, V2G operations could potentially decrease electric rates.

Increasing electric load growth, and hence sales, without requiring additional capital investment by the utility generally results in lower electric rates for utility customers, assuming that there are no additional cost increases due to reliability or grid maintenance. The recent study from Pacific Northwest National Laboratory validates this prediction for large penetrations of PEVs.[204] In some utility territories, the costly upgrades necessary to accommodate additional load on the distribution system

may offset part of this economic benefit. But where the benefit outweighs the increased distribution system costs, the lower cost can be passed on to all customers in the form of lower general electric rates, rebated to PEV owners through low PEV-charging rates, shared with utility shareholders, or some combination thereof.
Technical and cost characteristics for V2G operations, however, are still highly uncertain. Primary uncertainties include methods of communication between PEVs and electric grid operators, how to aggregate multiple PEV loads to amount to sellable bundles of electricity, and how to bill or financially account for the electricity that PEV owners dispatch back to the grid. Another drawback is that there may be less expensive ways to provide these same ancillary services. Existing loads such as electric water heaters could provide similar services by controlling the rate of electricity provided. Large, stationary battery packs are much less expensive than the premium batteries required for the stressful conditions in a vehicle life of 10 or more years.

Despite the many benefits that PEVs theoretically could provide via V2G initiatives, these remaining uncertainties, until resolved, limit the opportunities for V2G operations in the near-term. Continued research on these topics as they develop in demonstration pilots will help confirm the technical approach and clarify the extent of economic benefits associated with V2G.

Regardless of V2G potential, the advent of PEVs is expected to generate a variety of innovative retail electricity rate structures as utilities seek to offer incentives to PEV owners that charge during off-peak hours. Different rate structures include time-of-use rates, specific PEV-charging rates, or fixed monthly fees for PEVs. Time-of-use rates offer lower costs for off-peak and night charging. Specific PEV-charging rates are already in place in several utility territories. Some utilities, such as Consumers Energy and DTE Energy, are proposing fixed monthly fees for recharging PEVs.[205] Thus, the deployment of PEVs is likely to reinforce some reforms in electricity pricing and rebates that are already underway for other reasons.

Electricity Resources and Greenhouse Gas Emissions. There is a small but growing literature on the potential impact of PEVs on electricity demand and the resulting impacts on greenhouse gases from power production. The current blend of electricity sources in the United States is heavily concentrated with fossil fuels, particularly coal and natural gas, though this varies by location.

In 2008, coal and natural gas accounted for 48.7% and 21.5%, respectively, of U.S. power production.[206] The coal share is near zero on the West Coast and well below average in the Northeast. The Midwest and South have above-average dependence on coal. While the operating lives of existing nuclear power plants in the United States have been extended, the rate of investment in new nuclear plants is so modest and the lag time to operation so long that the nuclear share of the U.S. electricity market will at best remain stable for the next 20 years. Wind and solar power are steadily increasing their market shares from a very small base.

PEVs diminish or eliminate greenhouse gas emissions from the vehicle, but they induce more greenhouse gas emissions from electric power plants. Modeling studies suggest that, given the current mix of electricity sources in the United States, the net effect of PHEVs compared to current gasoline engines is a significant net reduction in greenhouse gas emissions.[207] However, when compared to HEVs, PEVs powered by the current mix of electricity sources are not a clear-cut improvement.[208,209] As long as the electricity sector continues to depend on carbon-intensive fossil fuels to satisfy the bulk of electric power, the environmental promise of the PEV industry will be limited. Projections for the greenhouse gas emissions of future PEVs are optimistic, however, showing improvements that result in a 7% to 46% reduction in greenhouse gas emissions compared to an HEV by 2050.[210]

Findings

There are promising prospects for advancements in battery technology that improve performance and reduce costs, and breakthroughs in advanced battery chemistries remain a distinct possibility. Significant cost reductions in battery technology have already been achieved. Additional battery R&D may achieve even greater cost reductions, perhaps more

significant than the cost reductions expected through economies of scale and "learning by doing" in the production process. While refinements of lithium-ion battery technology may prove sufficient for mass commercialization of PHEVs, a new type of energy storage will likely be required so that BEVs can satisfy the cost and range preferences of mainstream consumers.

BEVs have some clear advantages over PHEVs: They offer greater potential for energy-security benefits by eliminating the vehicle's use of petroleum; they have no tailpipe emissions; they eliminate the complexity and cost of the internal combustion engine; and the electric drive system is relatively simple to design, produce, and service. However, the obstacles to mass commercialization of BEVs are even greater than the obstacles for PHEVs. Given the high cost of battery production, a BEV that approaches affordability (with generous tax credits) has a driving range of about 70–100 miles on a full charge. The battery pack takes a long time to fully recharge (usually overnight), and even using an expensive commercial recharger takes considerably longer than refilling a standard gasoline tank. Although typical daily travel patterns in the United States lie well within the 100-mile range, most vehicle purchasers desire a full-function vehicle that can meet their predictable peak travel demands (i.e., their longest trips, such as weekend and holiday road trips). With its battery pack complemented by a small gasoline or diesel engine, a PHEV can make use of the existing refueling infrastructure to achieve driving ranges of 300 miles by featuring conventional refueling capabilities in addition to recharging the battery. An affordable BEV cannot match this range or speed of refueling, so BEVs may not achieve mass commercialization until there are breakthroughs in battery technology, though they may succeed in niche markets such as commuter vehicles for affluent multi-vehicle households or urban pick-up and delivery vehicles.

A comprehensive environmental evaluation of PEVs must consider the fact that production of electricity will generate risks to the environment that will vary in nature and magnitudes depending on the source of power. The potential impacts of PEVs on climate change are of particular concern. Given the current mix of electricity sources in the United States, use of a PEV will emit far fewer greenhouse gases than the current average gasoline engine, but may not be any better than HEVs that do not need to be recharged. As long as electricity production depends heavily on high-carbon energy sources, the net effect of PEVs on greenhouse gases will be limited and will vary by region. As electricity production shifts to lower carbon-emitting sources, the environmental promise of PEVs will be enhanced significantly.

PUBLIC POLICIES TOWARD PEVs

There are many obstacles facing the mass commercialization of PEVs, but the fact that a product may struggle commercially is not sufficient grounds for government intervention on the product's behalf. In the case of PEVs, some government action is warranted due to the negative environmental and security impacts of conventional vehicles, as well as the private sector's consistent underinvestment in R&D caused by the inability of firms to capture all the benefits generated by their R&D efforts.

The energy and vehicle markets fail to allocate resources efficiently because costs are imposed on third parties without their consent or compensation, a so-called "negative externality."* For example, tailpipe emissions and energy security costs from petroleum use impose external costs on individuals not involved in the purchase, sale, or use of the vehicle. Public policy offers a potential mechanism of "internalizing" such external costs (e.g., through fees on emissions of pollution).

R&D generates "positive externalities" because there are "spillover" benefits on external parties that are not accounted for in the market. Under the condition of a positive externality, suppliers and manufacturers will likely under-invest in innovative initiatives to offer PEVs because they are undercompensated for their efforts; benefits to other entities will occur since the information from innovation is readily used or adopted by others.[211] Intellectual property laws are designed to reduce positive externalities, but they are recognized to be an imperfect instrument, even in countries that have well-enforced property laws. Considering technical knowledge as a public good,** an efficient allocation of public funds is achieved through expenditures that achieve the greatest positive externalities from innovation.[212] Private underinvestment in R&D is the primary justification for public policy designed to stimulate private R&D through instruments such as low-volume production grants and loan guarantees, tax incentives, and public-private partnerships. A similar rationale is used for taxpayer support of governmental R&D programs.[213]

Another positive externality arises as the net value of a PEV increases with increased commercialization, also known as a "network effect."*** This occurs via direct and indirect positive externalities.**** The PEV market has a network externality because PEVs require a recharging infrastructure.[214] Additional purchases of PEVs give rise to more accompanying infrastructure, which in turn increases the net value of a PEV by improving the availability, performance, and affordability of such infrastructure. The indirect effect occurs as increases in the number of PEVs sold presumably leads to increased production, thereby lowering the unit price of PEVs. This effect is premised on the assumption that economies of scale in the PEV supply chain lower unit production costs. Economies of scale have been documented repeatedly in the manufacturing sector, especially at relatively low production volumes. Under these circumstances, firms have an incentive to "free ride" on the efforts of their competitors to attract demand for an innovative vehicle. The inevitability of some network externalities suggests a role for public policy in the early stages of PEV commercialization when infrastructure development is nascent, production volume is low, and unit production costs are highest.

Before surveying current public policies, it is useful to consider the attributes of policy instruments that may be of interest to policymakers. Five attributes may be of particular interest because they have ramifications for economic efficiency or political feasibility.

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*An "externality" exists when the production or consumption of a market actor enters the production or utility function of another entity without permission or compensation of that entity. See: Kolstad, C. 2000. *Environmental Economics*. Oxford University Press, Inc., New York.

**Pure public goods are neither rivalrous nor exclusive (Bickers and Williams 2001). R&D has some public good properties in that the use of technical knowledge by one entity does not diminish the ability of others to use it. Additionally, the creator of a new technology or knowledge cannot prevent others from using it. See: Bickers, Kenneth N. and Williams, J.T. 2001. *Public Policy Analysis*. Houghton Mifflin Company, Boston, MA.

***Liebowitz and Margolis (1994) define a network effect as "the circumstance in which the net value of an action is affected by the number of agents taking equivalent actions." See: Liebowitz, S.J. and Margolis, S. 1994. "Network Externality: An Uncommon Tragedy," *Journal of Economic Perspectives* 8, 133-150.

****Katz and Shapiro (1986) distinguished direct and indirect network externalities by whether or not there was "a direct physical effect of the number of purchasers on the quality of the product." See: Katz, M. L., and Shapiro, C. 1986. "Technology adoption in the presence of network externalities," *Journal of Political Economy* 94, 822-841.

Impact on Technology

A policy instrument that explicitly favors a specific technology (e.g., a government subsidy for new plants that build PEVs) is different from a policy instrument that encourages PEVs in a technology-neutral manner (e.g., a gasoline or carbon tax). While economists tend to favor technology-neutral policies on grounds of economic efficiency, politicians may favor instruments with a technological bias because it is easier to build political support and earn political credit when the bias is clear. A seemingly technology-neutral program, such as federal mileage standards for new cars, may in practice have a technological bias depending on the strictness of the requirements, the deadlines for compliance, and the current state of competing technologies.

Impact on Government Budget

Fiscally strapped governments at all levels need to know what the impact of an instrument will be on governmental revenues and expenditures. Grants for new battery manufacturing plants are a direct government expenditure, while government loan guarantees create financial risk. Other policies influence revenues to the government. A consumer tax credit for PEV purchasers reduces government revenue. More subtly, widespread use of PEVs would be a large threat to federal highway funds since the gasoline tax is a major source of these funds.

Impact on Consumer Budget

Policy instrument choice also has ramifications for the economic well-being of consumers and may have important political implications. Despite the attractiveness of a policy instrument that does not negatively impact government budgets, these instruments often negatively impact consumer budgets instead. For example, command and control regulations may be cheaper to implement for the government, but costs automakers incur in complying with regulations may be passed on to consumers. Similarly, consumer tax credits have a positive impact on a consumer's after-tax income while reducing government revenues.

Targets of Behavioral Change

Policy instruments differ in whose behavior they are trying to change. Production subsidies and vehicle mileage standards are aimed at vehicle manufacturers. Consumer tax credits for the purchase of new PEVs seek to influence the purchasing decisions of new vehicle buyers. Higher gasoline taxes encourage different choices by both vehicle producers and vehicle buyers.* While the initial target of behavioral change may be the consumer (e.g., a tax on gas guzzlers), manufacturers are likely to respond to policies that alter consumer preferences.

Nature of Incentives

There is a temptation to think of all incentives as financial (e.g., a tax credit for the consumer or producer). Yet some policy instruments deploy non-financial incentives to induce behavioral change. For example, by offering PEV owners access to coveted parking spaces in urban areas, government can encourage vehicle owners to purchase and use PEVs.

In surveying government policies toward PEVs, TEP has found it useful to compare the policies using these five attributes. TEP makes no simple claim, however, that there is a clear relationship between one or more attributes and a policy's desirability. Furthermore, the mix of policy instruments does vary in countries around the world, and U.S. policymakers may find it useful to consider the mix of policy instruments and associated attributes.

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*Note that in the United States, gasoline taxes are primarily used to maintain the existing network of transportation infrastructure, and are thus akin to a user fee. Although the intention is not to discourage driving, higher gasoline taxes could have this effect by raising the cost of automobile use.

Policy Instrument Options

TEP identified 10 different instruments that are being considered by policymakers to spur—directly or indirectly—the electrification of the transport sector. These instruments are summarized and then classified according to the five attributes (see Table 8).

Advanced Battery Warranties or Buyback Guarantees

Considerable consumer anxiety surrounds the issue of potential battery failure within the vehicle's lifetime. Batteries are very expensive to replace, so a warranty to protect consumers against this expense may be desirable. Buyback guarantees that ensure financial compensation for the depleted battery act as a safeguard against this concern. However, the incentive for battery suppliers to invent a durable long-life battery is reduced if the government will pay for a replacement.

"Feebates"

A feebate program combines a tax and a rebate. A certain level of fuel economy is set as the feebate "pivot point"—purchasers of vehicles below this point pay a tax while purchasers of vehicles above the point receive a rebate. Feebates may also be designed to create a middle zone; purchasers of near-average fuel economy vehicles would pay neither a tax nor receive a rebate.[215]

Federal Fleet Purchasing Agreement

The federal government is a large purchaser of new vehicles. To improve economies of scale, reduce the risk of PEV production in an uncertain market, and lead by example, the federal government has the option to enter into federal procurement agreements with makers of PEVs.

Preferential Parking and Vehicle Access

Sales of HEVs were boosted when HEVs were granted access to HOV lanes on crowded highways. This policy can be expanded to include PEVs. PEVs can also be given preferential parking access in downtown areas or be allowed into urban centers that restrict entry for other vehicles.

Table 8. Typologies of Policy Instrument Characteristics

	Impact on Technology	*Impact on Government Budget*	*Impact on Consumer Budget*	*Primary Policy or Regulatory Target*	*Incentive Type*
Vehicle and Charger Tax Credits	Specifying	Revenue-Decreasing	Positive	Consumers	Financial
Production Mandates	Neutral[1]	Revenue-Neutral	Negative	Automakers	Non-pecuniary
Community Demonstration Pilot Grants	Specifying	Revenue-Decreasing	Neutral	Local and Regional Governments	Financial
Preferential Parking and Vehicle Access	Specifying	Revenue-Decreasing[2]	Neutral	Consumers	Non-pecuniary
Battery Warranties and Buyback Guarantees	Specifying	Revenue-Decreasing	Positive	Consumers	Middle Ground
Federal Fleet Purchasing Agreement	Specifying	Revenue-Decreasing	Neutral	Automakers	Financial
Taxes on Oil Use or GHGs	Neutral	Revenue-Increasing	Negative	Consumers	Financial
Feebates	Neutral	Revenue-Neutral	Varied	Consumers and Automakers	Financial
Advanced Battery R&D Subsidies	Specifying	Revenue-Decreasing	Positive	Supply Chain	Financial
Vehicle Related Fee Reductions	Specifying	Revenue-Decreasing	Positive	Consumers	Financial

[1] Although the policy is technology-neutral, the level at which mandates are set may be influenced by the technologies currently on the market or which are favored by the policymakers.

[2] Decrease in revenue is modest compared to other policy instruments that decrease revenue, especially vehicle and charger tax credits.

Subsidies for Advanced Battery Research and Development

The government, especially the DOE, is already heavily involved in funding PEV-related R&D. With the costs of batteries remaining high, increasing R&D in this field could lead to significant cost-reducing advances that might spur PEV production and sales.

Community Demonstration Pilot Grants

This instrument choice involves providing grants to communities based on their readiness for PEV deployment. Readiness can be judged on criteria such as ease of the permitting process, existing incentives for PEV purchases, and coordination with local utilities. Grants can also be used for improving readiness, such as installing public recharging infrastructure.

Tax Incentives for Purchase of Vehicles and Recharging Equipment

Tax incentives aim to reduce the incremental cost of a PEV purchase compared to a conventional vehicle. Such price reductions arguably increase the likelihood that consumers will purchase PEVs. Tax incentives can also be deployed to lower the cost of recharging equipment for businesses or consumers.

Taxes on Oil Use or Greenhouse Gases

This policy instrument is currently in existence: Taxes are paid on the gasoline to fuel internal combustion engines (ICEs). Currently, this tax serves as a user fee by paying for road infrastructure projects and maintenance. The tax rate requires adjustment to capture the cost of the negative externalities created by oil consumption. Increasing the tax rate on fossil fuels would give PEVs and other alternative vehicles a stronger operating cost advantage over conventional vehicles. A different approach would be to tax oil imports or emissions of greenhouse gases from vehicles.

Vehicle Production Mandates

A command-and-control policy instrument, vehicle production mandates require auto manufacturers to sell a specified number of low-emission or technology-specific vehicles, regardless of market demand.

Vehicle-Related Fee Reductions

Policymakers can reduce the financial burden of purchasing a PEV in less direct ways than providing incentives at the point of purchase. Some options include reducing PEV registration fees and tolls or providing an "operating cost allowance" to cover expenses such as vehicle maintenance.

PEVs: A Presidential Pledge

Public policy interest in the future of PEVs has evolved over multiple presidential administrations. In 2007, for example, then-President George W. Bush instructed federal agencies to purchase and operate PHEVs for government business once they become commercially cost-competitive with non-PHEVs. However, President Barack Obama has given more priority to PEVs than has any previous president.

During his campaign in 2008, then-Senator Obama announced intentions to:

- "Invest in Developing Advanced Vehicles and Put 1 Million Plug-in Electric Vehicles on the Road by 2015;"[216]
- increase federal spending to leverage private sector funds and back domestic automakers in an effort to commercialize PHEVs and other advanced vehicles;

- invest in advanced vehicle technology, particularly R&D in advanced battery technology; and
- ensure that half of all car purchases by the federal government are PHEVs or BEVs by 2012.

The singular focus on PEVs displayed by the Obama campaign differed markedly from both the policies of the George W. Bush administration and the campaign position of presidential candidate Senator John McCain.

In surveying federal policies related to PEVs, TEP found that the Obama administration has made significant policy changes in four areas: purchasing of PEVs by government fleets, income tax credits for PEVs, federal mileage and carbon regulations, and financial assistance for PEV manufacturing and R&D.

Government Fleet Purchases

In signing Executive Order 13514, President Obama required federal agencies to reduce annual petroleum consumption by 2% per year from a 2005 baseline through 2020, resulting in a 30% total reduction. To fulfill a requirement of the order, the U.S. DOE issued a Federal Fleet Management Guidance document in April 2010. One strategy outlined in the document is to reduce fuel use and GHG emissions by purchasing PEVs.[217]

Income Tax Credits

Working with PEV advocates in the Congress, President Obama has also expanded the tax incentives for the purchase of PEVs. During the Bush administration, the Energy Improvement and Extension Act of 2008 provided a tax credit of $2,500 for PHEVs meeting a minimum battery size comparable to a PHEV with a 10-mile all-electric range. Several provisions in the American Recovery and Reinvestment Act (ARRA) of 2009 (the so-called “stimulus package”) have enlarged the tax credits for PEVs to as much as $7,500 per PEV (see Table 9).

Federal Fuel Economy and Greenhouse Gas Emissions Standards

In May 2009, the Obama administration issued a joint ruling from the Department of Transportation and the EPA, which raised the existing federal Corporate Average Fuel Economy (CAFE) standards and aligned them with new greenhouse gas emissions standards. CAFE standards for new cars and light trucks were raised from an industry average of 25 miles per gallon in model year 2010 to 35.5 miles per gallon in model year 2016. The EPA GHG regulation compels automakers to achieve a 30% reduction in greenhouse gas emissions from new vehicles by 2016.[218] The Obama administration has announced plans to further tighten these rules for model years 2017 through 2025.

The strictness of the new mileage standards are similar to what then-President George W. Bush proposed to the Congress in his State of the Union address in January 2007. With regard to PEVs, what is notably different about the Obama rules is a program of “advanced technology credits” that was not present in Bush’s policies. In particular, the EPA GHG standard includes a temporary provision aimed at fostering the initial commercialization of PEVs. The key language states:

> In this program, manufacturers who produce advanced technology vehicles will be able to assign a zero gram per mile CO_2 emissions value to the first 200,000 vehicles sold in model years 2012-2016 (for PHEVs, the zero gram per mile value applies only to the percentage of miles driven on grid electricity), or 300,000 vehicles for manufacturers that sell 25,000 vehicles or more in model year 2012. The CO_2 emissions compliance levels for advanced technology vehicles sold beyond these cumulative vehicle production caps will account for the net increase in upstream CO_2 emissions relative to a comparable gasoline vehicle. EPA will reassess the issue of how to address advanced technology vehicle emissions in future rulemakings for MY2017 and beyond, based on the status of their commercialization, upstream GHG control programs, and other factors.[219]

Table 9. PEV Provisions of the American Recovery and Reinvestment Act of 2009

Plug-in Electric Drive Vehicle Credit (§1141)	Amount: minimum amount is $2,500 with a top credit of $7,500 depending on battery size (beyond four kWh capacity, additional $417 per kWh available). Full credit amount will be reduced after the manufacturer has sold 200,000 vehicles. Qualifications: · Newly purchased after December 31, 2009 · Four or more wheels · Gross vehicle weight rating under 14,000 pounds · Propulsion system uses battery with at least a four kW capacity that is rechargeable from an external electric source
Plug-in Electric Vehicle Credit (§1142)	Amount: 10% of the cost of the vehicle up to $2,500 for purchases made between February 17, 2009 and January 1, 2012. Qualifications: · Either a low speed electric vehicle that uses at least a four kilowatt hour battery or a two or three-wheeled vehicle with an electric motor that uses at least a 2.5 kWh battery · Taxpayer cannot claim credit if §1141 credit is allowable
Conversion Kits (§1143)	Amount: 10% of the cost up to $4,000 of converting a vehicle to a qualifying plug-in electric drive motor vehicle. Qualifications: · Does not apply to conversions after December 31, 2011 · Taxpayer can claim credit even if claiming a hybrid vehicle credit for the same vehicle in a previous year
Alternative Fuel Vehicle Refueling Property Credit	The Energy Policy Act (EPAct) of 2005 (Pub. L. No. 109-58, §1342) provided an income tax credit of 30% of the cost of installing new alternative fuel vehicle refueling property at each location by a taxpayer (capped at $30,000 for business property and $1,000 for residence). The ARRA increases the credit from 30% (capped at $30,000 for business property and $1,000 for residence) to 50% (capped at $50,000 for business property and $2000 for residence) for property placed in service in 2010. If the refueling property is acquired by a tax-exempt organization, governmental unit, or a foreign person or entity, and the use of that property is described in section 50(b)(3) or (4), the company that sold the fueling equipment can claim the tax credit if they provide the customer with written notification of the credit value.

PEV Infrastructure and R&D Subsidies

Financial assistance for vehicle manufacturers began during the Bush administration and has been expanded by the Obama administration through DOE's Advanced Technology Vehicle Manufacturing Loan Program and the Electric Drive Vehicle Battery and Component Manufacturing Initiative. Specifically, in the fall of 2008, Congress appropriated $25 billion in manufacturing loans, and DOE responded in June 2009 with $8 billion in loans to Nissan, Ford, and Tesla.[220]

The manufacturing loan program was an open and competitive process. Loans were provided to vehicle or component manufacturers that increase fuel economy by 25% or more relative to 2005 levels. While Congress did not restrict DOE support to PEVs, the initial recipients are all pursuing transport electrification in conjunction with other fuel economy enhancements. For example, Ford was loaned $5.9 billion to help retool plants in the Midwest for 13 fuel-efficient models, including production of 5,000–10,000 electric cars beginning in 2011. Nissan was loaned $1.6 billion to help build 100,000 electric cars at a new plant in Smyrna, Tenn., starting in 2013.

In August 2009, the Obama administration took a step further and allocated $2.4 billion in stimulus funds to battery technology development, $1.5 billion to manufacturing capacity expansion, $500 million to recycling capacity development for lithium batteries, and $400 million for infrastructure concepts (including recharging infrastructure).[221]

Under the Electric Drive Vehicle Battery and Component Manufacturing Initiative, DOE used a competitive process to select 30 projects involving the manufacturing of batteries and electric drive components. The initiative will lead to more than $4 billion in investments since grant recipients are required to match the government's contribution. DOE awarded about 90% of the $400 million under the Vehicle Electrification Initiative to 11 grant recipients supporting deployment and integration projects in dozens of locations nationwide. Funds will help offset the costs of vehicle purchasing and the installation of recharging infrastructure.

In April and August of 2009, DOE announced $777 million for Energy Frontier Research Centers over a span of five years.[222] These centers include national laboratories, universities, nonprofit organizations, and private companies. The effort targets the acceleration of scientific breakthroughs in a variety of energy technologies that include transportation and electricity storage.

Later in August 2009, DOE announced awards totaling $300 million in the Clean Cities program: a cost-share program that aims to put 9,000 electrified, alternative, and fuel-efficient vehicles on the road.[223] The government-industry partnership matches every federal dollar with nearly two from project partners. Eight of the 25 projects fund PEVs or related infrastructure.

State and Local Policies[224]

Many states have introduced their own incentive programs to encourage the production, purchase, and use of electric vehicles. The most popular policy instrument used by states is a tax incentive aimed at reducing the incremental cost of purchasing an electric vehicle. These incentives can take the form of a rebate, an income tax credit, or a sales tax exemption. California, Colorado, Georgia, Illinois, Louisiana, Maryland, New Jersey, Oregon, Oklahoma, South Carolina, Utah, and Washington have incentives that range from a $750 income tax credit (Utah) to a rebate of up to $20,000 for commercial PEVs (California). Recently, Tennessee also announced a rebate of $2,500 on the first 1,000 PEVs sold in the state.[225] New Jersey and Washington offer state sales tax exemptions for BEVs, a policy that DOE models suggest is quite effective at stimulating sales of BEVs.[226] Washington offers PHEVs a more modest exemption from its 0.3% motor vehicle tax.

Montana has chosen to offer a tax incentive of $500 for the conversion of a vehicle to run on electricity, but has not added any incentives for the purchase of a new electric vehicle. Similarly, Florida has used stimulus money to fund the conversion of 100 Priuses to run on electricity. Utah offers a larger tax credit for those who convert their existing vehicle than for those who buy a new electric vehicle ($2,500 compared to $750). Georgia, Illinois, Louisiana, and Oregon offer conversion tax credits of equal or lesser value compared to the tax credits they offer for vehicle purchase.

Another popular option for states is policy that encourages manufacturing of PEVs or their batteries in the state. Implemented by Indiana, Michigan, Louisiana, New Mexico, Oklahoma, South Carolina, and Pennsylvania, these policies include property tax exemptions, tax credits for purchasing manufacturing equipment, and tax credits based on kilowatt hours of battery capacity produced. Several of these credits are not specifically targeted to promote PEVs, but apply to the manufacture of all alternative fuel vehicles. Other states, mainly in the Midwest and Plains states, have alternative fuel credits, but exclude electricity from their definition of "alternative fuels." A related option is to provide incentives or grants for R&D to improve PEV technology, such as those now in place in Michigan, Vermont, California, and Wisconsin.

Several states have chosen to subsidize recharging infrastructure for PEVs, both at home and on the go. Arizona provides a $75 tax credit for the installation of home recharging outlets. Colorado provides recharging infrastructure grants to local governments based on the municipality's energy efficiency record, and Virginia has a similar program. Louisiana offers a tax credit for 50% of the cost of constructing an alternative fueling station.

Washington, in particular, has developed a suite of infrastructure policies that strongly encourage PEV use. Washington sales and use taxes do not apply to labor and services for installing, repairing, altering, or improving PEV infrastructure (the same exemption applies to batteries) or to the sale of property to be used for PEV infrastructure. All regional transportation planning organizations that encompass a county with a population of 1 million or more must collaborate with state and local governments to invest in PEV infrastructure and promote PEV use generally. Additionally, the state must provide PEV recharging infrastructure at all state rest stops and fleet parking and maintenance facilities by 2015. Local governments are required to develop regulations that allow the installation of PEV infrastructure, contingent on federal funding. Washington allows leasing of state land for Better Place-style battery-switching stations for 50 years and exempts these stations from certain environmental regulations.

States have also adopted policies to ease or reduce the auxiliary costs and inconveniences of driving a car powered by electricity. Arizona has reduced the license fee for BEVs and some PHEVs. Florida provides PEV owners with exemptions from most insurance surcharges. Washington exempts PEVs from emissions inspection requirements. An especially common practice is to allow single-rider PEVs to occupy HOV lanes—Virginia, Maryland, and California are among the states to adopt this policy. Delaware has a unique approach to offsetting costs of a PEV: it has passed a law requiring that PEV owners be credited for electricity provided to the grid by the car battery at the same rate that the owner is charged for electricity use.

Finally, states have opted to provide grants and loans to local governments for various activities that will promote use of PEVs. These activities include electrifying school buses, purchasing PEVs for municipal fleets, and installing recharging infrastructure.

Local governments are also working to encourage their residents to purchase PEVs. The City of Austin's public utility provides a rebate of $150–$500 to customers who buy an electric car, scooter, bicycle, or motorcycle.[227] The City of Portland has adopted a strategic plan for PEVs, which includes streamlining electrical permitting, providing consistent signage for recharging points, making the municipal fleet more sustainable, and providing PEV recharging for homes without garages.[228] New York City provides grants to private firms and nonprofit groups for up to 50% of the incremental cost of purchasing a PEV. Houston has a similar program for governmental or private firms, and Dallas has a grant program for reducing taxi emissions. The City of New Haven, Conn. provides free parking on city streets to all alternative fuel vehicles. Washington, D.C. exempts all vehicles that achieve more than 40 miles per gallon from the excise tax imposed on an original certificate of title, while the town of Warren, R.I. allows excise tax exemptions of up to $100 for qualified alternative fuel vehicles registered in the town. This sampling of local initiatives reveals that PEV promotion policies can be found at all levels of government (see Figure 4).

State and local policies receive less national attention than presidential executive orders or new legislation from Congress. Nevertheless, state and local actions can have significant impacts. Compliance with California's ZEV mandate, all by itself, is projected to compel industry to produce at least 58,000 PEVs per year by 2016.[229] In addition, when state rebates are combined with the federal tax credit, the affordability of a PEV improves markedly.

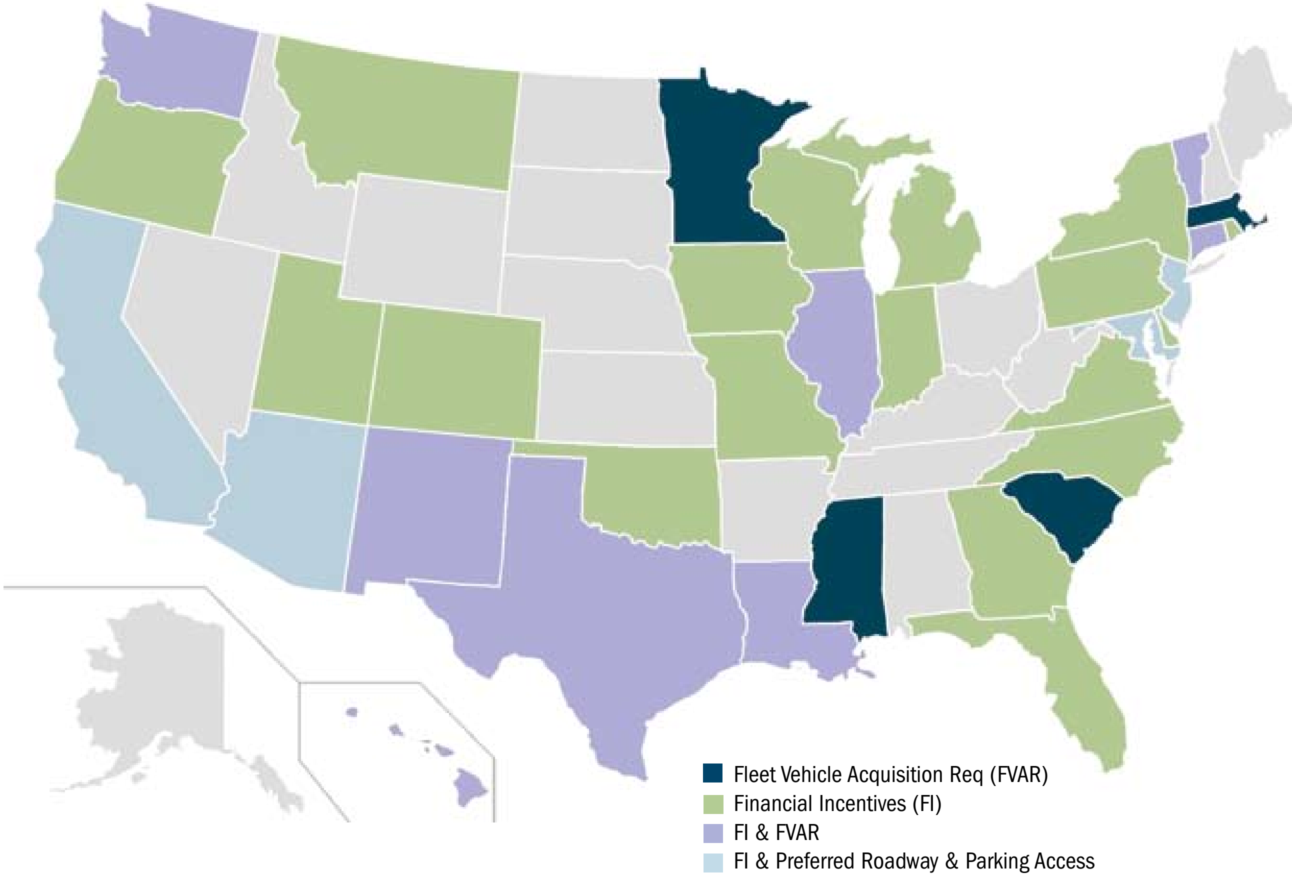
An International Perspective on Policy

Virtually all developed countries as well as China and India are instituting policies to stimulate production of PEVs. These policies include investment in R&D, subsidies for vehicle purchase, recharging infrastructure improvements, deployment initiatives, technology-specific and technology-neutral policies, and programs that help promote the growth of domestic PEV industries and/or achieve broader environmental goals.

International Transportation Contingencies

Two major factors affecting global demand for PEVs are gasoline prices and public transportation, Figure 5 shows trends in gasoline prices in major world cities in June 2010. Figure 6 compares national average retail gasoline prices for countries in Western Europe and the U.S. since 1996. By and large, gasoline price behavior has exhibited similar trends across these places. Retail gasoline prices had little fluctuation through 2001, dropped in the worldwide recession in 2001-03, then rose steadily again until the worldwide recession of 2008. After that collapse, prices have begun to rise again.

Figure 4. State Laws and Regulations Affecting PEVs



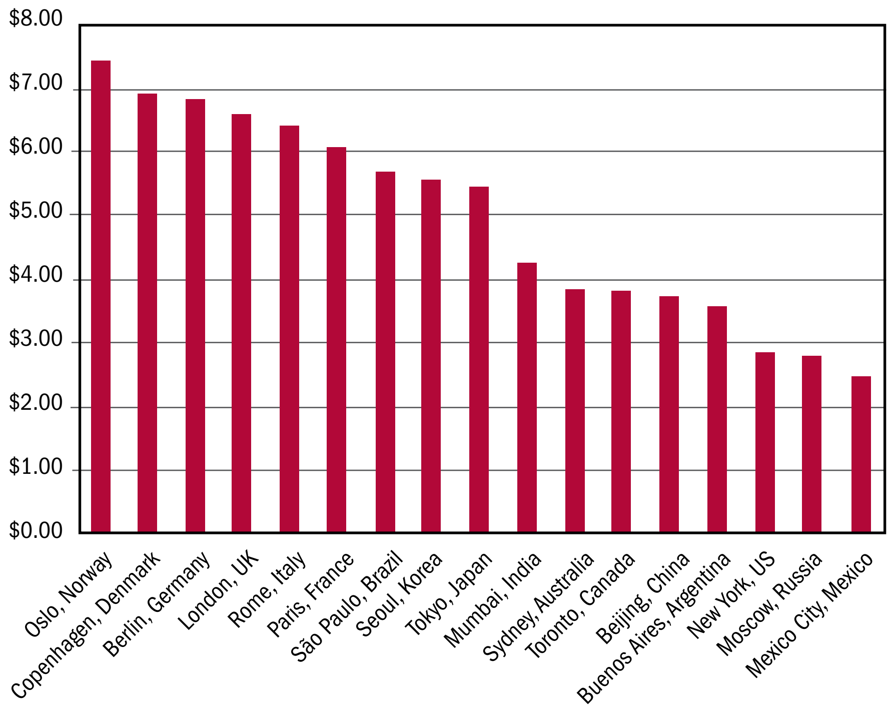
Source: The Pew Center on Global Climate Change. *Plug-in Electric Vehicles*. Accessed December 5, 2010. Available from: http://www.pewclimate.org/what_s_being_done/in_the_states/plug_-_in_electric_vehicles

High gasoline prices are likely to increase PEV demand and encourage production, especially if prices surpass a threshold point where the purchase premium for PEVs is fully offset by the savings due to the lower costs of electricity. Worldwide demand for petroleum and crude oil products continues to increase, while the supply of fossil fuels is finite and remaining supplies are located in places that can be difficult to access. On the other hand, the efficiency of fossil fuel use continues to improve, and major improvements to the internal combustion engine are expected to protect consumers somewhat from unexpected increases in gasoline prices. Higher gasoline taxes have been recommended by many experts, but they are difficult to pass in elected legislatures. Gasoline taxes are already high in Europe and are generally considered too politically unpopular to increase in the United States.[230] Furthermore, much of the funding for transportation in countries comes from the gasoline tax, and increasing PEV use would result in decreasing tax revenues for governments.

The effect of mass transit systems on the PEV industry is more difficult to predict. The use of public transportation and PEVs might be competitive with one another, particularly among choice riders of transit who live in dense urban settings and are environmentally conscious. These travelers may prefer the flexibility of PEVs over the rigid timetables and routes of public transit. There is an opposite line of argument that mass transit users are from an entirely different population. Many people use mass transit because they cannot afford vehicle ownership and operation and are even less likely to pay the expected initial price premiums for PEVs.

Mass transit availability varies widely across the globe. In the United States, mass transit operates as a limited social service in most cities outside of the West and East Coasts. Some cities have instituted ambitious plans to reinvigorate mass transit, usually in the form of light rail, and encourage transit-oriented development. While these systems have often

Figure 5: Average Gasoline Prices in Major World Cities, 30 June 2010



Adapted from Lewis, L. July 22, 2010. *Gas Prices Around the World: What It Costs to Fill 'Er Up*. DailyFinance. Available from: http://www.dailyfinance.com/story/gas-prices-around-the-world/19543148/

been successful, they are limited in scope,[231] and the overwhelming majority of transportation trips in the United States remain in passenger vehicles.[232]

The most advanced transit environments in the world are in European countries and Japan. In these countries, transit accessibility is very high and in some places exceeds automobile accessibility. These countries also lack the social stigma and negative attitude toward transit that is found in the United States. Nonetheless, automobile ownership and use have been increasing for two decades in Europe at rates similar to that in the United States.[233] China and India are not yet dependent upon the automobile, but offer less advanced forms of mass transit. China is steadily building a national high-speed rail network and expanding fixed route urban transit systems; but both countries are still highly reliant on motorbus and small-vehicle public transit. Despite the interest in alternatives to cars, the demand for automobiles in China and India is booming. Walking and bicycling are also much more common outside the United States and are used for some of the short-haul trips for which PEVs are potentially targeted.

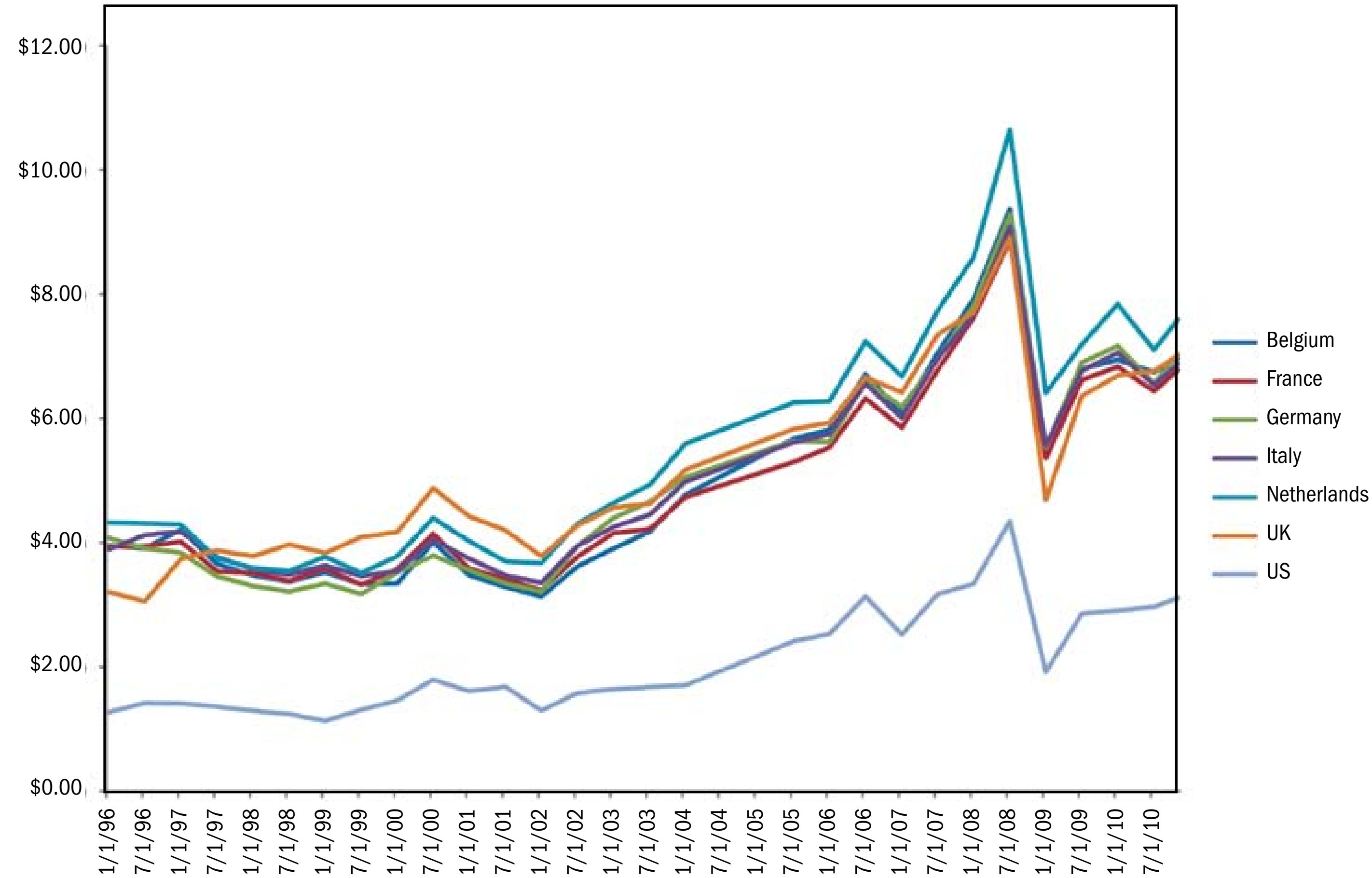
European Union Policies

Despite the popular impression of Europe as a green, non-automotive transport environment, motor vehicles constitute a significant portion of travel across the continent. The transportation sector is responsible for 19% of greenhouse gas and 28% of CO_2 emissions in the EU, of which 90% is attributed to road transportation. Since 1995, car ownership has increased by 22% and auto use by 18%. Not surprisingly, CO_2 emissions from the automotive transportation sector are up 27% since 1990.[234]

The EU recently required that 10% of transportation fuels come from renewable sources by 2020.[235] The prevailing view is that any new electricity demand should not be met by fossil fuels. Biofuels are viewed as a vital component of renewable fuel targets, but there are concerns over the net greenhouse gas emission savings from biofuel sources and the impact on deforestation and farmland. Nuclear energy, after being shunned by most countries for several decades (France is a notable exception), is increasingly being seen as a potentially viable clean generator of electricity. Sweden and Germany are beginning to reconsider the future of nuclear power plants in their nations' power systems.[236]

A significant incentive for the adoption of PEVs in EU member states comes from the high taxes on fuel. While the U.S. federal gasoline tax has rested at a flat rate of $0.184 per gallon (before state taxes—which vary widely—are added), [237] in European countries up to 75% of the cost of gasoline is made up of taxes.[238] PEVs are currently excluded from this tax. Thus, EU fuel taxes represent a dramatic cost incentive for PEVs, much more so than in the United States.

Figure 6: Gasoline prices of US and Selected Western European Countries, 1996 to 2011*



*Adapted from Weekly Retail Premium Gas Prices. Energy Information Administration. Available from: www.eia.doe.gov/emeu/international/gas1.xls

There are concerns among environmental groups and activists in Europe over the alleged bias of policymakers toward adoption of PEVs. Many see the EU's preference for vehicle ownership and driving as unsustainable and would prefer to see continued initiatives for managing land use and investing in public transportation, walking, and biking infrastructure. There is concern that the adoption of PEVs will lead to net increases in certain sectors of energy consumption that will only exacerbate existing pressures on the environment.

Generally, EU policy incorporates PEVs as a component of a larger scheme to meet EU targets for reducing CO_2 emissions 20% by 2020. Vehicle manufacturers are required to limit average CO_2 emissions to no more than 130 g/km.[239] Added to this minimum is a "limit value curve" that determines allowable emissions by car tonnage. This policy design gives additional leeway to manufacturers who produce a heavier fleet of vehicles. Policy updates are requiring automobile manufacturers to produce gradually increasing proportions of their fleet below the 130 g/km figure, reaching 100% of vehicles produced by 2015.[240]

Recent EU transport policies emanate from the Green Car Initiative, which is a component of the European Economic Recovery Plan of November 2008.[241] It provides for €1 billion (~$1.3 billion U.S.) in R&D for "greening" road transportation plus an additional €4 billion (~$5.3 billion U.S.) in European Investment Bank (EIB) loans for technological innovation.[242] The initiative also calls for the introduction of demand-side measures to reduce GHGs and public procurement policies to stimulate production and sale of low-CO_2-emission vehicles. The scope of research and procurement includes BEV and

PHEV batteries, engines, recharging systems, and grid infrastructure for both passenger cars and trucks. It also supports greener internal combustion engines, bio-methane, hydrogen, and fuel cells.[243]

The Spanish Presidency of the Council of the EU (January–June 2010) identified electrification as the key approach to de-carbonizing road transportation. The European Commission established a vision of de-carbonizing the European energy system by 80% by 2050 and ending oil dependence for the transportation sector through its Second Strategic Energy Review.[244] Support for this vision comes from the Strategic Energy Technology (SET) Plan, which includes urban mobility projects that focus on transport electrification.

The EU's technological and industrial arms have a roadmap in place for industry to produce five million PEVs in the EU and for annual sales to reach 1.5 million vehicles by 2020. To reach these targets, the SET Plan identified infrastructure and market development as key supporting policies. The EU is moving to standardize the recharging mechanisms for batteries and stations across all member states by 2017. The EU is also allocating monies for adoption incentives and public procurement of PEVs to help develop a critical mass of market demand that would otherwise be impractical for member states to achieve on their own.[245] However, there is no EU-wide monetary incentive to purchase a PEV similar to the $7,500 tax credit in the United States. Table 10 summarizes EU policy directions.

The "deployment community" approach to test the rollout and feasibility of PEVs is also a centerpiece of EU policy. Starting in 2011, the European Commission will launch "e-mobility" demonstrations in Barcelona, Berlin, Bornholm, Copenhagen, Cork, Dublin, Karlsruhe/Stuttgart, Madrid, Malaga, Malmo, Pisa, Rome, and Strasbourg. Each demonstration is small (10–3,000 PEVs, 50–4,000 recharging spots) but some have DC fast-charging stations, smart grid features, battery-switching schemes, and billing systems.[246] Thus, while the EU has appeared to be more technology-neutral than the United States, the EU is gradually adopting more PEV-specific policies.

EU Member-State Policies[247]

Initiatives from EU member states generally fall into one of several categories: infrastructure support, monetary and regulatory incentives for market adoption, public procurement of the vehicles, R&D subsidies, and domestic and international

Table 10: EU Policies Toward PEVs

Policy Categories	*Policies and Initiatives*
Regulation	Manufacturers fleet average of 130 g/km CO2 emissions with adjustments based on vehicle weight 65% of fleet by 2012 75% of fleet by 2013 80% of fleet by 2014 100% of fleet by 2015
Monetary Incentives	Registration tax reductions for low-carbon vehicles Circulation tax reductions for low-carbon vehicles
Public Procurement	Encourage public procurement of low-carbon vehicles
Infrastructure	Mandate for standardized recharging stations throughout EU through 2017
Research	500 million funding for research 500 million matching from industry and EU member states 4 billion in additional EIB loans for industry innovation PEV and hybrid cars target of Green Car Initiative funded research SET Plan focus on accelerated development and deployment of low-carbon technologies

Summarized from: *Green cars initiative. European Commission: Research and Innovation—Transport.* Accessed January 17, 2011. Available from: http://ec.europa.eu/research/transport/info/green_cars_initiative_en.html standardization of key technological components. Most regulations focus on CO_2 emissions measured in grams per kilometer emitted from the vehicle, and fees on these are levied at the collection of registration and circulation (excise or licensing) taxes. Rather than a national distribution of vehicles, incentives, and recharging centers, most policies seem to focus on testing these vehicles in selected urban areas.

Many countries have also established national targets for PEV production. These are summarized in Table 11. BEV and PHEV goals of EU member states add up to over 2.5 million new vehicles by 2020, approximately a 15% market share.

State-level policies are widespread in Europe, and a summary of initiatives appears in Table 12. Key alliances between the PEV industry and member-state policies are found in France, Germany, Portugal, and the UK. France has deployed several policies to encourage development and adoption of PEVs. The government has announced plans to purchase 50,000 PEVs.[248] The French government has worked closely with the Renault–Nissan partnership to fund and develop PEV technology and has committed €900 million (~$1.2 billion U.S.) for recharging infrastructure.[249] For consumer adoption, the first 100,000 passenger and light-commercial vehicles classified as "green," which would be comprised largely of PEVs, are eligible for a €5,000 (~$6,700 U.S.) credit through 2012.[250] The tax on company cars has also been modified to account for emissions levels of the vehicle, implicitly favoring PEVs.

The administration of German Chancellor Angela Merkel has recently rolled out a National Electromobility Development Plan for the incorporation of PEV production into the German economy. This plan largely focuses on R&D, and on establishing an understanding of market dynamics for the vehicles.[251] Nearly €1 billion (~$1.3 billion U.S.) is being contributed by the German government, either directly or in association with industry consortiums, toward PEV R&D, demonstration projects, and battery development. Germany is launching its own "e-mobility" demonstration program with a different focus in each of the participating regions: Hamburg, Oldenburg, Rhein-Ruhr, Rhein-Main, Stuttgart, Munich, Dresden, Leipzig, and Potsdam/Berlin. About 2,600 vehicles from 30 manufacturers, including 2,500 recharging spots, are part of the effort.[252] Car tax policies have been modified to favor PEVs with exemption from the emissions tax for five years, and all cars categorized as "green" are permanently exempt from the tax. But these tax breaks are quite small compared to the large PEV purchase incentives now in place in the United States and France.[253]

The United Kingdom has deployed an array of policies to both encourage vehicle adoption and to stimulate economic growth through industrial development and location. PEVs are exempt from the circulation tax and parking fees in London, Manchester, and Richmond. They are also exempt from the congestion charge in central London.[254] For two years ending in 2012, a subsidy of up to £5,000 (~$7,900 U.S.) is available for the purchase of a PEV.[255] The government has further planned the implementation

Table 11: PEV Production Targets in EU Member States

Country	*Target*	*Technology*	*Date*
Denmark	100,000	PEV and HEV	2012
	200,000	PEV and HEV	2020
France	2,000,000	PEV and HEV	2020
Germany	1,000,000	PEV	2020
	5,000,000	PEV	2030
Ireland	350,000	PEV and HEV	2020
	40% Market Share	PEV and HEV	2030
Netherlands	10,000	PEV and HEV	2015
	200,000 (100% stock)	PEV and HEV	2040
Spain	1,000,000	PEV and HEV	2014
Sweden	600,000	PEV and HEV	2020
Switzerland	145,000	PEV and HEV	2020
United Kingdom	1,200,000	BEV	2020
	350,000	PHEV	2020
	3,300,000	BEV	2030
	7,900,000	PHEV	2030

Adapted from: Hacker, F., Harthan, R., Matthes, F., and Zimmer, W. 2009. "Environmental impacts and impact on the electricity market of a large scale introduction of electric cars in Europe: Critical Review of Literature." *ETC/ACC Technical Paper 2009/4*, July 2009. European Topic Centre on Air and Climate Change. Brussels.

Table 12: EU Member-State Policies Toward PEV

Location	*Policy Instruments*	*Policies and Initiatives*	*Status*
Austria	Monetary incentives	CO_2 based fuel consumption tax (> 160 g/km) €500 credit for purchasing alternative fuel vehicle	In place
		Electric car mobility card, car leasing, maintenance, and free recharging	Pilot projects
	Research	E-connected initiative to link stakeholders and share information	In place
Belgium	Monetary incentives	15% purchase price reduction up to 4,540 for green car (< 105 g/km) 3% purchase price reduction up to €850 for 105 <> 115 g/km	In place In place
		Wallonia: up to €1,000 bonus for cars < 105 g/km Wallonia: up to €1,000 penalty for cars > 195 g/km	In place In place
	Public procurement	Wallonia: €2 million to buy PEVs for municipalities	In place
Cyprus	Monetary incentives	30% reduction in registration tax for green car (<120 g/km)	In place
		15% reduction in annual circulation tax for green cars (<150 g/km)	In place
		€683 credit for purchase of new PEVs	In place
Denmark	Monetary incentives	Clean cars free of all taxes (180% registration tax, 25% VAT)	Planned
		Free parking for PEVs	In place
		PEVs free from registration tax	In place
	Infrastructure	€100 million to increase recharging speed and accessibility Cooperation between Danish energy corporation DONG and Better Place	Planned
	Research	€5.6 million to integrate recharging PEVs with wind power generation	In place
	Public procurement	€4 million PEV fleet trial program	In place
France	Monetary incentives	€5,000 credit for first 100,000 purchased green passenger cars and light-commercial vehicles (< 60 g/km) through 2012	In place
		Progressive company car tax: low of €2 per gram emitted < 100 g/km to high of €19 per gram emitted > 250 g/km	In place
		Free parking spaces for PEVs	Planned
	Public procurement	5,000 HEVs and PEVs	In place
		50,000 PEVs for fleet use	Committed
	Standardization	National recharging network set-up	In place
	Research	€400 million fund for R&D and demonstration projects for vehicle development and recharging infrastructure	Committed
Germany	Monetary incentives	€500 million program to support pilot projects, research, development of battery technology and vehicles	Committed
		€60 million (additional €360 mil¬lion by industry consortium) R&D for lithium-ion batteries	Committed
		Linear tax of €2 per 1g/km Green cars exempt (< 120 g/km) PEVs five years no tax	In place In place In place
	Infrastructure	Recharging stations in Berlin and other “e-mobility” cities	In place
	Standardization	Common standard for plug	Planned
Greece	Monetary incentives	No car registration or road tax for PEVs and HEVs	In place
	Non-monetary Incentives	Exclusion of circulation restriction	In place
Ireland	Monetary incentives	Progressive vehicle registration tax: low 14% for cars < 120 g/km to high of 36% for cars > 225 g/km	In place
		€2,500 tax credit for hybrid and flexible fuel vehicles Exemption from registration tax for PEV through 2010	In place In place
		Progressive circulation tax: low €104 for cars < 120 g/km to €2,100 for cars > 225 g/km	In place

Table 12 (cont'd): EU Member-State Policies Toward PEV

Location	*Policy Categories*	*Policies and Initiatives*	*Status*
Italy	Infrastructure	670 public and private recharging stations	In place
	Public procurement	100 PEVs in Rome, Milan, and Pisa	In place
Norway	Monetary incentives	Exemption from car registration tax, VAT and annual car tax for PEVs	In place
		Exemption from parking fees and congestion charges for PEVs	In place
		Free use of bus lanes and ferryboats b/t national roads for PEVs	In place
Portugal	Monetary incentives	PEVs are exempt from circulation and registration tax €1,000 maximum credit for purchasing green car (< 140 g/km)	In place
	Infrastructure	320 recharging stations by 2010 1,300 recharging stations by 2011	Planned Planned
Spain	Monetary incentives	15% rebate at purchase of an PEV or HEV	In place
		Progressive registration tax: < 120 g/km exempt; 121 <>160 g/km 4.75%, 161 <> 200 g/km 9.75%, > 200 g/km 14.75%	In place
	Infrastructure	500 recharging stations	In place
	Public procurement	2000 PEVs	In place
Sweden	Monetary incentives	SEK 10,000 credit for PEV and HEV purchase	In place
		Progressive circulation tax: SEK 15 per g/km above 100 g/km, sum multiplied by 3.15 to 3.3 for diesel cars SEK 10 per g/km above g/km for alternative fuel vehicles	In place
		Exemption from congestion charge in Stockholm for PEV and hybrid	In place
	Infrastructure	€1.5 million investment in recharging infrastructure	In place
		500 recharging points	Planned
United Kingdom	Monetary incentives	Progressive circulation tax: low of £0 at 100 g/km, high of £400 at > 225 g/km	In place
		Exemption from parking fees in London for alternative fueled vehicles Parking fees and permits tied to vehicles emission level Exemption from parking fees in Richmond and Manchester for EV	In place In place In place
		No congestion charge in London £2,000 to £5,000 subsidy for PEV purchase 2011-2012 £250 million plan to promote low carbon transportation for 2010-2015	In place In place Committed
	Public procurement	£20 million procurement program of low-carbon vehicles 100 PEVs launched in urban areas	Planned Planned
	Infrastructure	25,000 recharging points in London	Planned
		Dedicated bays for car club PEVs in London £20 million for infrastructure (and technology research)	Planned
	Standardization	Support development of standards for recharging infrastructure	Committed
	International collaboration	Develop international standards for recharging infrastructure	Committed
	Research	£350 million for demonstration projects, research	Committed

Table adapted from Hacker, F., Harthan, R., Matthes, F., and Zimmer, W. 2009. "Environmental impacts and impact on the electricity market of a large scale introduction of electric cars in Europe: Critical Review of Literature," *ETC/ACC Technical Paper 2009/4,* July 2009. European Topic Centre on Air and Climate Change. Brussels. Updated from EurActiv, June 30, 2010. EU mandates standard plug for electric cars. Available from: http://www.euractiv.com/en/transportation/eu-mandates-standard-plug-electric-cars-news-495754.

AND Loveday, E.,May 3, 2010. *French government announces plans to order 50,000 electric vehicles, offers incentives to buyers.* AutoBlogGreen. Available from: http://green.autoblog.com/2010/05/03/french-government-announces-plans-to-order-50-000-electric-vehic/.

AND IDC Energy Insights. July 6, 2010. *New Italian Regulation Will Help Electric Vehicle Development, IDC Energy Insights Says*. Available from: http://www.idc-ei.com/getdoc.jsp?containerId=prIT22409910&sessionId=

of 25,000 recharging points in London by 2015[256] and the procurement of £20 million (~$30 million U.S.) in low-carbon vehicles for government fleet use.[257] The UK is partnering with Nissan to establish a production plant and testing sites for low-carbon vehicles and is lobbying to have the LEAF manufacturing operations headquartered in Sunderland.[258]

PEVs in Portugal are encouraged through exemption from road taxes,[259] and the first 5,000 purchasers of a PEV will receive a €5,000 subsidy (~$6,500 U.S.).[260] Portugal is also in the process of making public access to recharging stations widespread with 1,300 recharging stations to be completed by the end of 2011. The end goal is to have the first standardized, nationwide recharging infrastructure in Europe.[261] Like the UK, Portugal is partnering with Nissan to establish production plants for the LEAF and other cars in the country.[262]

China

China's 1.4 billion citizens are currently driving only 30 million vehicles, which makes the rapidly developing country the world's largest untapped automobile market.[263] China's status as the automobile market of the future was further cemented when it recently passed the United States in annual new automobile sales.* The central government favors motorization of society as a vital aspect to development and likewise views the vehicle market as a fertile one that Chinese manufacaturers have yet to penetrate. State control over private sector direction and energy supply, including fuel prices at the pump, makes China a very different environment for PEV innovation than the EU or the United States.

China's home-grown automakers lag significantly behind the rest of the world in their ability to produce quality petroleum-fueled vehicles. Chinese officials view any attempt to innovate in the traditional automobile market as futile as it could never hope to gain a technological advantage over its seasoned foreign competitors. Consequently, innovation into the new market of PEVs represents the best opportunity for Chinese companies to compete in the worldwide automobile market, which currently lacks any dominant PEV producers. Additional motivations for PEV development include energy independence and urban air pollution mitigation. Domestic petroleum production in China appears to have peaked. While 75% of electricity production is from coal-burning plants, the central government of China feels the removal of auto emissions from gasoline-powered vehicles has the potential to reduce the severe air pollution within its fast-growing cities.[264]

The Chinese Ministry of Industry and Information Technology is currently preparing a 10-year plan to become the worldwide leader in the PEV market. [265] This plan includes building between three to five automobile companies and two to three battery companies into major competitors in their markets, where China currently lacks any such penetration.** Components of this plan include short-term national production goals for 500,000 to one million energy-efficient vehicles by 2015. By 2020, there are expectations for the production and deployment of five million BEVs, PHEVs, and other alternative fuel vehicles, and an additional 15 million HEVs. The combined 20 million passenger vehicles represents a 10% market share of Beijing's expected 200 million passenger cars in China by the end of the decade.***

Beijing has also announced a 100 billion Yuan (~$14 billion U.S.) program to subsidize and encourage the development and adoption of PEVs and alternative fuel vehicles in China. [266] This program includes commercialization of more fuel-efficient powertrains; demonstration programs; infrastructure for alternative vehicles; incentives for the purchase of green vehicles; and funding directly to vehicle, electric motor, and battery manufacturers.

As in the United Kingdom and Japan, a primary component of the initiative is a pilot program for subsidization of the purchase of PEVs. Five cities have been selected for the program: Hefei (population: 5 million), Changchun (7.7 million),

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*Lewis, L. January 12, 2010. "China passes U.S. as worlds' biggest car market." *The Sunday Times*. Available from: http://business.timesonline.co.uk/tol/business/industry_sectors/transport/article 6984166.exe

**Shirouzu, N. September 16, 2010. "China Spooks Auto Makers." *The Wall Street Journal*. Available from: http://online.wsj.com/article/SB10001424052748704394704575495480368918268.html?KEYWORDS=china+electric+vehicle+policy

***People's Daily Online. *China's auto ownership is expected to exceed 200 million in 2020*. September 6, 2010. Available from: http://english.peopledaily.com.on/90001/90778/90860/7131189.html

Hangzhou (8.1 million), Shenzhen (8.9 million), and Shanghai (23.2 million). Under the program, up to 60,000 Yuan (~$8,800 U.S.) is available toward the purchase of a BEV, 50,000 Yuan (~ $7,600 U.S.) for a PHEV, and 3,000 Yuan (~$460 U.S.) for an HEV or a conventional gasoline vehicle with an engine smaller that 1.6 L in cubic displacement.[267] Unlike many purchase rebate policies, here the rebate goes to the vehicle manufacturer, who then reduces the cost of the car sold by the size of the rebate. The manufacturer's purchase subsidy is subject to downscaling once the manufacturer's annual production capacity reaches 50,000 PEVs.[268]

In addition to the national subsidy program, three of the pilot cities are offering further incentives for the purchase of PEVs. Shanghai is offering a reduction of 40,000–60,000 Yuan (~$6,000–$9,100 U.S.) off the purchase price, while Shenzhen residents are eligible for a subsidy of 30,000 Yuan (~$4,600) for a PHEV and 60,000 Yuan (~$9,100 U.S.) for a BEV.[269] Residents of Jilin, the province where Changchun is located, are eligible for a 40,000 Yuan (~$6,000 U.S.) reduction for purchase of a PEV.[270]

The central government is also funding the construction of recharging infrastructure and has ordered its electric utility and grid companies to prepare for the integration of the target number of PEVs into electric demand. Four thousand recharging stations are targeted for construcion by the year 2015 and 10,000 by the year 2020.[271] The recharging infrastructure and battery mechanisms are being developed in conjunction with the state's oil companies, who view the PEV and battery industry as a new business opportunity for a state that imports more than 50% of the crude oil it consumes.[272] Public transportation is additionally seen as a focus for conversion to electric and alternative energy as well, with a pilot program for clean energy public transportation vehicles targeted for 20 cities.

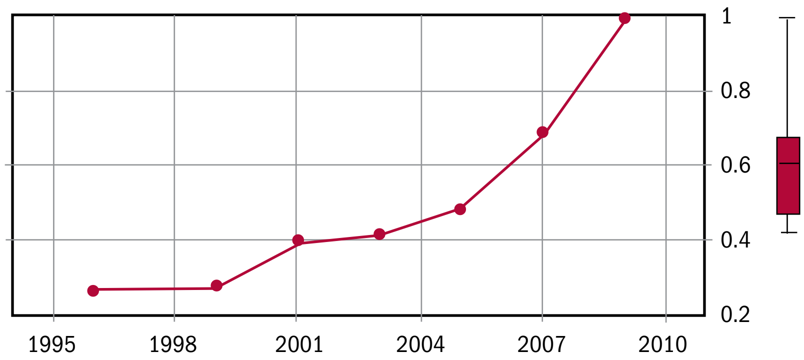
Another key component of China's development of PEVs is international collaboration. In late 2009, the United States and China announced a joint PEVs initiative, designed to stimulate the exchange of technological advancement between the two countries.[273] The initiative calls for joint development of common design standards for plugs and test protocols for batteries. Also planned are joint demonstrations of PEV programs in at least 12 cities in the two countries to collect and share data on recharging patterns, driving experiences, grid integration, and consumer preferences. The initiative proposes the creation of a joint taskforce, which will produce a multi-year roadmap to guide R&D needs and pinpoint key issues in manufacturing, introduction, and use. The roadmap is designed to be a living document, regularly updated to reflect technological advancement and marketplace evolution. In addition, the first "U.S.–China Electric Vehicles Forum" will become an annual event with the host alternating between the two countries to facilitate the meeting of key stakeholders, information sharing, and development of new arenas for the exchange of best practices.[274]

Despite significant advancements in PEVs, obstacles to their adoption in China remain. One of these has been Chinese influence over domestic oil and gasoline prices. China has long controlled domestic gasoline prices through regulation of state-owned petroleum refining and gasoline distribution companies. This has resulted in an artificially low price of gasoline for consumers, which encourages consumption and development. However, the changing dynamics of automobile production and ownership have also meant changes in China's energy policy.

Recent policy changes include the adoption of a new fuel pricing system to mitigate the effects of increased integration between Chinese and worldwide production and consumption of petroleum. Policy was introduced in December 2008 to make Chinese oil and gasoline prices in line with worldwide retail prices. This was done with the introduction of a formula used to alter prices set by the National Development and Reform Commission of China to make adjustments to the retail price of gasoline whenever a baseline set of international crude oil prices change by more than 4% over the course of 22 consecutive working days.[275] The pricing structure includes a cap at $80 per barrel, where the formula may be modified or the retail price of gasoline left alone.[276] This structure has resulted in 10 fuel price adjustments between December 2008 and May 2010, and a notable increase in gasoline prices paid by automobile users, as seen in Figure 7.[277]

The pricing policy was partly motivated by the global recession in 2008, when the international crude price skyrocketed. This caused refiners to cease production, so as not to sell at a loss, and created a shortage in supply that further disrupted

Figure 7: China – Pump Price for Gasoline (U.S. Dollar per Liter)



Source: Data from TradingEconomics.com. Available from: http://www.tradingeconomics.com/china/pump-price-for-diesel-fuel-us-dollar-per-liter-wb-data.html

the market. China is also concerned about mitigating potential inflation in its currency and sees energy price manipulation as a way to control the value of the Yuan. [278]

An additional component of the oil pricing reform is a change in the source of transportation revenues, which previously came from fees collected from local authorities. These have been replaced with a consumption tax and a value-added tax for gasoline and diesel. There are also carbon taxes levied in 13 western provinces to help narrow income gaps between that region and the coastal provinces.[279] The policy change is also expected to increase tax revenues from transportation to mitigate travel demand and to collect revenue with which to finance other transportation initiatives.

International collaboration with China may face roadblocks. The proposed 10-year plan contains a requirement that foreign companies wishing to sell PEVs in China engage in technology-sharing if they produce components in China (which would be a virtual certainty in the PEV market). The specifics call for these companies to form joint ventures with Chinese counterparts and cap foreign ownership in these ventures at 49%. This would give Chinese companies access to foreign technological innovations that would otherwise be the exclusive property of the patent-holding innovators.[280] This proposal is similar to other trade, currency, and technological standards set by China in an effort to motivate indigenous innovation of industry. In effect, state controls are being used to gain access foreign intellectual property and to position Chinese companies at a competitive advantage.

The potential consequences of Chinese companies capturing the PEV market have major implications for worldwide automobile production. China currently has more than 100 automotive companies[281] and Chinese designs for its economy and society involve both the motorization of Chinese citizens in Chinese-produced PEVs as well as the exporting of those PEVs to consumers internationally. China, which is currently limited in domestic and international battery production and small in automobile production, is positioning itself at the forefront of those industries.

Japan

Japan has a relatively long history of government support for alternative-energy vehicles, dating back to a leasing program for local governments and private businesses that began in 1978. Japanese policies include subsidies, public procurement, R&D grants, demonstration programs, tax incentives, regulation, standardization, and public education. In 1997, national targets were set for 200,000 PEVs, 1.8 million HEVs, and 1 million CNG vehicles by 2010.[282] The Ministry of Economy, Trade, and Industry in Japan has since updated these goals with aggressive targets of 50% of all new domestic vehicle sales in 2020 to be from electric and conventional hybrid models.[283]

Japan began using public procurement policies for PEVs in 1998. Since then, the national government has steadily replaced the national fleet of 7,000 civilian vehicles with PEVs and low-pollution vehicles. The recent recession has stimulated recent initiatives to further facilitate the production and adoption of PEVs. Japan recently completed a program designed to incentivize the replacement of older vehicles with newer, greener models, including PEVs. The program ran from mid-2009 to mid-2010 and offered a rebate of up to 250,000 Yen (~$2,700 U.S.) when trading in a car that was more than 13 years old for the purchase of a PEV, other alternative-energy vehicle, or a high-efficiency vehicle.[284] Also offered under the program was a 125,000 Yen (~$1,500 U.S.) rebate with no trade-in on the purchase of any new PEV, other alternative-energy vehicle, or high-efficiency vehicle.[284] Also offered under the program was a 125,000 Yen (~$1,500 U.S.) rebate with no trade-in on the purchase of any new PEV, other alternative-energy vehicle, or high-efficieny vehicle. Under a three-year program from mid-2009 through mid-2012, PEVs and HEVs are exempt from the country's sales tax and the annual operating tax (quantified by the weight of the vehicle). Low-emission vehicles and mini-cars also receive a tax rebate of 75%.

Japan is also working to develop infrastructure for recharging stations, and battery-switching appears to have gained greater traction here than elsewhere. A pilot program organized through Better Place and the Economic Ministry of Japan has been running battery swaps in taxis since April, and the trial period was recently extended.[285] In 2010, Japan has also invested approximately $140 million in recharging infrastructure.

South Korea

South Korea has become a major player in the battery market, with domestic companies Samsung and LG holding 38% of the world market share. South Korea seeks to further establish itself in this market with enhanced domestic production of component technology and parts. The recently announced Battery 2020 Project allots $12.5 billion for battery R&D to increase the percentage of domestically manufactured component parts from 20% to 75%.[286]

Despite wielding significant influence in the battery world, South Korea has, until recently, had limited utility for PEVs. BEVs have been banned in South Korea on safety grounds, and alternative-energy vehicles were focused on hybrid technology. The ban is being replaced with policies to instigate further R&D and to stimulate consumer demand for all kinds of PEVs.[287]

The overarching goal of South Korean national policy is to eliminate dependence on foreign sources for energy. Currently 97% of power used in the country is generated outside of its borders and over half of that is from petroleum.[288] National policy in South Korea thus straddles incentives for battery industry, green industry, and technology-neutral development, as well as specific incentives for HEVs and BEVs. A major feature of South Korean policy is a recent $85 billion U.S. investment scheme for environmentally sustainable industries. This low-carbon and green growth investment constitutes 2% of current annual GDP and is hoped to create nearly two million new domestic jobs. Technology-neutral components of the scheme include introduction of a carbon trading credit system by 2012 and increasing fuel economy standards, a move that was prompted by the recent changes in U.S. standards and the desire to keep domestic automobile production in line with worldwide trends in fuel economy.[289]

South Korean automaker Hyundai is currently the world's fifth-largest automaker, and South Korea plans to become the world's fourth-largest producer of PEVs. National goals include transition of the domestic fleet of small-sized sedans to be made up of at least 10% PEVs by 2020. A 10% market capture of the HEV and PEV market is targeted by 2015, and eventual domestic goals include 1 million PEVs on South Korean roads.[290] Specific measures to achieve this goal include incentives for fleet purchases with a subsidy for PEV purchases by public offices of up to approximately $17,000 goal beginning in July 2011. [291] Other proposed incentives include exemption of BEVs from registration, consumption, and acquisition taxes on standard automobiles. These incentives would be in addition to existing incentives for the purchase of HEVs, and with a total savings equal to approximately $3,000 per vehicle. There is also a deployment initiative to connect PEVs and recharging stations in the South Korean capital of Seoul, focusing on access to recharging in public places, particularly stores and shopping centers, as well as prioritization in parking facilities for PEV owners.[292]

India

India has been among the world's leaders in small vehicle and PEV production for domestic use, with the REVAi, a small BEV, sold commercially since 2001. The REVAi's production was recently purchased by Bangalore-based Mahindra Reva. Several other Indian automakers, including Tata, Tara, and Ajanta, are also preparing to launch a PEV.[293] Electric scooters and buses are already popular in India, and approximately 1% of the existing vehicle fleet is electric-powered.

The PEV market so far has been limited to the REVAi, and producers are worried about their long-term viability and position in the global automobile marketplace, which in India is increasingly perceived as trending toward PEVs. However, government intervention and incentivization in India is quite limited in all sectors of the economy. Since the initiation of economic reforms designed to develop the free market in India beginning in the mid-1980s, the Indian government has removed most of its restrictions and subsidies in the automotive industry.[294] It is unclear how willing India will be to initiate government intervention in its fledgling automobile industry.

In 2010, India began development of a national PEV policy. As a result, the nation's industry and government commissioned a policy feasibility study in April 2010.[295] One of the policy components under consideration is the abatement of excise and state sales taxes. Nationally, an excise tax of 4% is levied on PEV production, while the imported materials for components of PEVs are levied at an additional 10% excise tax.[296] PEVs in Delhi, Rajasthan, Uttarakhand, and Lakshadweep are exempt from state sales tax; other states charge 4%–15% sales tax.[297] Initiatives for joint ventures, technology sharing and transfer, and increasing the number of recharging points in the country are also under consideration.[298]

Summary

Despite the many challenges facing proponents of PEVs, virtually every carmaker in every country in the world is planning some kind of PEV in the next five years, and this is occurring ubiquitously with assistance from national governments. Nearly all countries have established national targets for vehicle production in the next 10 years and are directing billions of dollars toward R&D of advanced technology and to policies that encourage vehicle deployment. While there has been no international treaty on PEVs, there appears to be a worldwide commitment to the commercialization of PEVs.

Findings

Recent public policies in the United States and other countries have improved the prospects for initial commercialization of PEVs. These policies include generous tax credits for consumers and producers, new regulations of vehicle manufacturers, special access to high occupancy vehicle (HOV) lanes and city parking, loan guarantees and subsidies for companies that produce advanced batteries and related components or assemble PEVs, grants for recharging infrastructure, and federal R&D support for more advanced battery technologies. Regulatory compliance with California's Zero Emission Vehicle (ZEV) program has been an influential driver of the recent product offerings by some automakers. Many countries have established short-term vehicle production targets comparable to those of the United States. Policies in some EU member states (e.g., France and the United Kingdom), China, and Japan focus directly on promoting PEVs, while the EU has focused on technology-neutral measures (e.g., carbon-emission limitations on new vehicle sales). Japan and South Korea have emerged as leaders in battery research and development, with the United States also becoming a significant R&D supporter.

PANEL RECOMMENDATIONS

The members of the Transport Electrification Panel offer the following policy recommendations that apply to the national, state, and local levels of government. In many cases, effective implementation will entail collaboration with the many stakeholders interested in PEVs.

1. *Technology-Neutral Policies*. Policymakers should generally pursue energy-security and environmental goals through technology-neutral policies, thereby allowing the marketplace for fuels and vehicles to determine which technologies are superior. The following fuel-saving policy instruments are typically considered technology-neutral: a gasoline tax; a national fuel efficiency standard that allows manufacturers to trade compliance credits; and a "feebate" incentive system for fuel efficiency, where buyers of high-mileage cars are awarded a rebate while buyers of low-mileage cars pay a fee. Policymakers must recognize that innovative, emerging technologies are at different stages along their learning and cost-reduction curves, and it is difficult for innovators, including commercial "first movers," to fully capture the benefits of their risk-taking. Thus, technology-neutral public policies will not always be technology-neutral in their practical effects. Some technology-specific policies are needed to allow emerging technologies to compete with mature technologies. If technology-neutral policies are not adopted—perhaps due to political opposition—and technology-specific policies are enacted instead, they should be designed to be as cost-effective as possible. Before any policies are enacted that might seem to promote PEVs specifically, the benefits of fleet electrification need to be compared to those from competing technologies. Given the technological and market unknowns, it may be wise for policymakers and businesses to invest in a mix of emerging technologies (non-PEVs and PEVs) until R&D and real-world experience establish which technologies are superior in specific applications. Any targeted public assistance for PEVs should be limited in both duration and production volumes. These programs should also be monitored and evaluated regularly to ensure accountability and effectiveness.

2. *National Demonstration of PEVs*. A federally supported, national PEV demonstration program should be implemented to help overcome the information barriers faced by the PEV industry today. A de facto demonstration is already underway as private and governmental efforts prepare target communities for PEVs. Yet these efforts have not been combined and coordinated in a focused national program aimed at "learning by doing." In order to resolve uncertainties about PEVs, it is crucial that the demonstrations gather data from consumers, dealers, manufacturers, utilities, retailers, and municipalities. Without key data, the opportunity to learn about the real-world experience with PEVs—successes, burdens, and mistakes—will be foregone, and unnecessary public uncertainty, confusion, and debate will continue. In the design of a cost-effective national demonstration program, the following program characteristics should be considered:

    - Focus on a limited number of designated communities (five to 20, depending on community size) with a range of climates, demographic and housing characteristics, public transit systems, and electric utility and regulatory systems.
    - A strong partnership among national laboratories, universities, municipalities, and private actors is needed to collect high-quality data. The demonstration communities and especially the data-gathering exercises within them must be large enough to support statistically significant sample sizes, and the original data and findings must be shared widely with researchers and practitioners.
    - In order for a demonstration community to provide useful data, it should have as many of the following characteristics as possible:
        - streamlined permitting procedures to facilitate recharging;
        - time-of-use data gathering and electricity pricing capability;
        - a priority placed on residential recharging infrastructure coupled with some workplace and community recharging;

- o guidance materials available about niche fleet markets where PEVs may be particularly promising because routes are short and recharging can be performed at a central location (e.g., urban pick-up and delivery vehicles);
- o data-gathering activity on vehicle purchasing and leasing, driving patterns, servicing and recharging behaviors, and the evolution of public perceptions and attitudes; and
- o action plans and evaluation activities that coordinate the vital roles of motorists, car dealers, automakers and suppliers, utilities, regulators, fleet buyers, and universities.

Such a demonstration program should be monitored by independent analysts to ensure that community demonstrations do not proliferate to the point that they represent a bias toward PEVs.

3. *Global Leadership Position in Technology, Manufacturing, and Public Policy*. The U.S. automotive, battery, and electric power industries, in collaboration with the U.S. government and universities, should seek to establish a global leadership position in electric mobility, especially in advanced energy storage technologies and production of batteries and related components. Constructive steps have already been taken toward fostering a U.S.-based supply chain for PEVs and expanding R&D into advanced batteries and other powertrain components. The track record of policies toward PEVs needs to be evaluated and, where necessary, refined as technology and market conditions change. Thus, the national demonstration and R&D program should be seen not just as a strategy to pursue worthy energy security and environmental goals, but also as a strategy to help revitalize the U.S. manufacturing sector.

4. *International Collaboration*. Although the focus should be on advancing U.S. leadership and competitiveness in this dynamic field, there is also a need for some international collaboration. Historically, different vehicle standards have been a barrier to international trade, making it difficult for companies to transfer innovations from one national market to another. The EU, Asia, and North America are adopting somewhat different technical procedures and public policies toward PEVs. Areas ripe for cooperation include codes and standards for recharging, approaches to measuring vehicle fuel efficiency, and emissions measurement, including test conditions. A regular international exchange of information about the formulation of successful PEV demonstrations and public policies is also appropriate. Since China and the United States have some common national interests in reducing petroleum use and have facilitated constructive corporate partnerships in vehicle technology and production, the China–U.S. dialogue on PEVs should be encouraged to continue, assuming intellectual property rights are respected.

5. *Cost-Effective Consumer Incentive Programs*. For investors in emerging technologies, there can be a "valley of death" between the market acceptance of early adopters and widespread commercialization. Without some public assistance through this valley, emerging technologies with long-term promise may be discarded prematurely. In this regard, PHEVs may be closer than BEVs to overcoming the valley since the current energy storage capabilities for BEVs are inadequate. While generous volume-limited tax credits have already been established for consumers who purchase a PEV (e.g., up to $7,500 at the federal level and an additional $5,000 in a few states), the following targeted, cost-effective measures to boost consumer demand for PEVs are worthy of consideration:
   - government and commercial fleet purchases;
   - PEV access to HOV lanes and parking in congested urban areas;
   - battery warranty adjustments or guarantees; and
   - targeted public information programs to dispel myths and reduce confusion.

6. *Support for Recharging Infrastructure*. Private investments in recharging infrastructure may prove to be too small to support adequate demonstrations due to high initial costs for recharging infrastructure, few "first mover" advantages, relatively low energy prices in the United States, long payback periods, and uncertainty about the volume of future PEVs on the road. Significant public funding of recharging infrastructure has already been appropriated, and it is not yet clear whether more funding is necessary. Since some retailers (e.g., shopping malls) may have adequate business incentives

to offer recharging stations to help attract and retain customers, relatively little infusion of public funds should be aimed at community recharging facilities. As additional public cost-sharing of recharging is provided, the cost-effectiveness criterion suggests that the highest priority should be residential recharging, followed by stations at workplaces, and then community stations. Excessive spending on community stations may result in severely underutilized infrastructure, which can damage public support for PEVs.

7. *Modernizing the Electric Power System*. Even a partial shift from petroleum to electricity as a transportation fuel will have ramifications for the operation and growth of the electric power system. Detailed knowledge of the power grid is required to ensure that outages are avoided. To optimize the benefits of electrification, public policies should be adopted to:
    - accelerate “smart grid” research, standards, and implementation;
    - expand the availability of lower electricity prices during off-peak periods to enhance consumers’ willingness to charge their vehicles at night, and include continuous, time-of-use pricing adjustments where acceptable;
    - increase the availability of metering, recharging, and vehicle technologies that will enable these time-of-use adjustments to electricity prices;
    - encourage or require enhanced efficiency and the movement toward a cleaner power generation system in order to reduce upstream emissions associated with PEVs in the form of greenhouse gases and conventional pollutants.

8. *Long-Term R&D Commitments*. Lithium-ion batteries may never have adequate energy density to independently power a household’s primary multi-purpose vehicle. Although there have been significant improvements in battery technology since the 1990s, policymakers should consider a large increase in federal R&D investments into innovative battery chemistries, prototyping, and manufacturing processes. A broader selection of R&D grantees, with even more vigorous competition, is appropriate compared to past practices. Sustained investment in R&D, including both public and private funds, is crucial as the United States seeks to establish a leadership position in the growing global market for advanced battery technologies and related components. The potential spillover benefits in the economy from R&D and manufacturing leadership deserve serious consideration by policymakers, even though public R&D decisions will be made in a troubled federal fiscal situation. In order to determine the appropriate scale of R&D expansion, the expected payoffs from long-term R&D investments in energy storage techniques should be compared to the anticipated payoffs from R&D investments in other advanced fuels and propulsion systems.

Countries around the world are jockeying for position in the emerging PEV industry. The time for the United States to secure a leadership position in the global market for PEVs is now. This report provides an expert panel’s view of how the United States can secure this role in a cost-effective manner.

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