

Electrification Roadmap

REVOLUTIONIZING TRANSPORTATION AND ACHIEVING ENERGY SECURITY



Electrification
Coalition

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Electrification Coalition

The Electrification Coalition is dedicated to reducing America's dependence on oil through the electrification of transportation. Our primary mission is to promote government action to facilitate deployment of electric vehicles on a mass scale. The Coalition serves as a dedicated rallying point for an array of electrification allies and works to disseminate informed, detailed policy research and analysis.

CURRENT COALITION MEMBERS

Timothy E. Conver

CHAIRMAN, PRESIDENT & CEO, AEROVIRONMENT, INC.

Peter L. Corsell

CEO, GRIDPOINT, INC.

David W. Crane

PRESIDENT & CEO, NRG ENERGY, INC.

Kevin Czinger

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Alex A. Molinaroli

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Reuben Munger

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Frederick W. Smith

CHAIRMAN, PRESIDENT & CEO, FEDEX CORPORATION

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PRESIDENT & CEO, A123 SYSTEMS, INC.

PREFACE

Electrification Roadmap

The Electrification Roadmap endeavors to serve a practical function: to provide a public policy guide to transforming the U.S. light-duty ground transportation system from one that is oil-dependent to one powered almost entirely by electricity.

The need for such a document arises from the tremendous difficulty of the task. The goal of deploying more than 200 million electric-powered vehicles is ambitious and should not be understated. The envisioned change demands synchronized deployment of new vehicles and infrastructure on a massive scale. The existing ground transportation system represents a century of private investment and government regulation, and fundamentally altering this system requires an exceedingly careful and thorough planning process, to which this report seeks to make a helpful contribution.

The timing of this report is deliberate. Federal and state policies are proceeding apace, and those efforts are historic in nature. Never before have so many resources been brought to bear in support of electrification of transportation. Nonetheless, there is a great risk that the results of these initiatives could be less than the sum of the parts. To secure the advantages of electrification, it is not enough to deploy even millions of vehicles. In fact, only penetration rates in excess of a hundred million electric vehicles will be sufficient.

Beyond the sheer number, the manner in which vehicles enter the system will prove crucial to achieving scale at the lowest public cost and with the least disruption. The electricity grid was not designed, and does not operate presently, as an aspect of the transportation system. It is one thing to sprinkle a modest number of electric-drive cars throughout a nation as large as the United States; it is quite another for even a seemingly small number of those cars to operate simultaneously in a specific area, let alone for millions to be densely concentrated in a single city. The recommended policies seek to ensure not only the production of vast quantities of electric vehicles, but also their seamless integration into a complex electricity grid and transportation network.

The companies and leaders who are signatories to this report affirmatively support the policy objectives and recommendations contained within. To maximize the comprehensiveness and cohesiveness of information and analysis, participants span the electrification value chain. Included are the perspectives of enterprises involved with raw materials, battery

production, vehicle manufacturing and marketing, power generation, and technology, among others. This structure reflects the view that electrification entails a systemic shift encompassing multiple industries and policies that depart markedly from the incumbent transportation network. Additional voices will be added in the coming months as the group refines its work and engages the policy-making process.

As independent private companies, each organization will pursue its own business plan; general statistics that are cited refer to industry-wide figures unless otherwise noted and do not necessarily speak to the specific circumstances or cost structure of any one company.

It is hoped that this report offers policymakers and the public a clear and accessible schematic for converting the vision of electrification into a working system that displaces oil as the nation's dominant transportation fuel and, in so doing, dramatically enhances energy security, propels economic growth, and reduces carbon dioxide emissions.

Ideally, the technology and deployment of electric vehicles would emerge through regular market mechanisms. Events conclusively demonstrate that this path to electrification is unlikely, however. Therefore, if the desired transformation is to occur anytime in the foreseeable future, focused and sustained public policy will be required. All of those who contributed to this document are committed to assisting policymakers at this critical moment in the history of electrification. The Electrification Roadmap represents the best efforts of the participants to provide the nation's leaders with accurate, timely, and actionable guidelines.

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Executive Summary

The United States may finally be emerging from its longest, and most severe, post-Depression recession.¹ Although the recession was driven primarily by turmoil in financial and housing markets, it is increasingly clear that rising oil prices were a significant factor as well.²

At the beginning of 2001, oil prices were steady at \$30 per barrel. Over the subsequent five years, prices steadily rose, reaching \$75 per barrel in June of 2006. After retreating slightly, benchmark crude prices jumped 50 percent in 2007, from \$60 per barrel in January to more than \$90 in December. In 2008, oil prices soared rapidly, eventually reaching their all-time high of more than \$147 per barrel on July 3.³

American households spent an average of \$3,597 on gasoline in 2008.⁴ Between 2001 and 2008, the average retail price of gasoline increased from \$1.46 to \$3.27,⁵ costing typical households \$1,990 a year in increased fuel expenses. By way of comparison, all changes to the federal tax code during that same period decreased annual federal income and estate taxes by about \$1,900 for the median household.⁶ In other words, every penny that the typical household saved due to federal income and estate tax cuts over the past eight years was spent on higher gasoline bills. These increased energy costs reduced nearly every family's discretionary income, diminishing their ability to spend, and contributing to a weakening of our consumer spending-driven economy.

The importance of oil to the U.S. economy is beyond dispute. Oil provides 40 percent of America's primary energy needs, more than any other fuel source.⁷ In large part, this is due to the scale and dynamism of the U.S. transportation sector, which consumes nearly 14 million barrels of petroleum each day—more than the total oil consumption of any other nation in the world.⁸ Americans enjoy a flexible, mobile lifestyle, and it is powered almost exclusively by oil. Our cars, trucks, planes and ships rely on oil for 94 percent of their fuel, and there are no meaningful substitutes currently available at anything remotely approaching scale.⁹ In 2008 alone, the United States spent more than \$900 billion on gasoline, diesel, and other petroleum products.¹⁰

This heavy reliance on petroleum has created unsustainable risks to American economic and national security. The economic risks are all too clear: so long as the cars and trucks that power our economy are dependent on a single fuel source, the majority of which is produced in hostile nations and unstable regions of the world and the price of which is increasingly volatile, our economy is at the mercy of events and actors largely beyond our control.

The fundamental factors that contribute to the increasing—and increasingly volatile—price of oil are likely to persist over the long term. Between 2007 and 2030, the International Energy Agency expects world oil demand to grow by 21.2 million barrels per day (mbd), with fully 100 percent of the increase coming from developing countries.¹¹ Rising demand for energy in China and India in particular has added a new dimension to the global oil consumption picture. With burgeoning middle classes and rapidly expanding economies, both nations appear poised to provide consistent pressure on world oil suppliers. In the meantime, resource nationalism, political instability, and insufficient upstream investment in many oil producing regions are continuing to constrain growth in oil supplies.

At the same time, the risk of a sudden and prolonged interruption to steady world oil supplies looms over the U.S. and world economies. Much of the infrastructure that delivers oil to the world market each day is exposed and vulnerable to attack in unstable regions of the world. According to the U.S. Department of Energy, each day more than 50 percent of the world's oil supplies must transit one of six maritime chokepoints, narrow shipping channels like the Strait of Hormuz between Iran and Qatar.¹² Even a failed attempt to close one of these strategic passages could cause global oil prices to skyrocket. A successful closure of even one of these chokepoints would bring economic catastrophe.

To mitigate this risk, U.S. armed forces expend enormous resources patrolling oil transit routes and protecting chronically vulnerable infrastructure in hostile corners of the globe. This engagement benefits all nations, but comes primarily at the expense of the

1 International Monetary Fund, *World Economic Outlook: Sustaining the Recovery* (October 2009) (hereinafter WEO 2009).

2 James D. Hamilton, *Causes and Consequences of the Oil Shock of 2007-08* (Apr. 2009) available at dss.ucsd.edu/~jhamilto/Hamilton_oil_shock_08.pdf (Working Paper).

3 U.S. Department of Energy, Energy Information Administration, *Petroleum Navigator, Petroleum Prices*.

4 Authors' calculation based on data from Department of Energy (DOE), Energy Information Administration (EIA), *Annual Energy Review 2008*, at 181 (table 5.24) (2009) (hereinafter, AER 2008).

5 Id.

6 Tax Policy Center, Urban Institute and Brookings Institution, *Individual Income and Estate Tax Provision in the 2001-08 Tax Cuts*, (Table T08-0147) (2008) available online at www.taxpolicycenter.org/numbers/displayatab.cfm?DocID=1856&topic2ID=150&topic3ID=157&DocTypeID=2, last accessed on August 19, 2009.

7 BP *Statistical Review of World Energy 2009*, at 41 (2009), available at (hereinafter, BP *Statistical Review 2009*).

8 Id.; AEO 2009, at 125 (Table A7), 131 (Table A11).

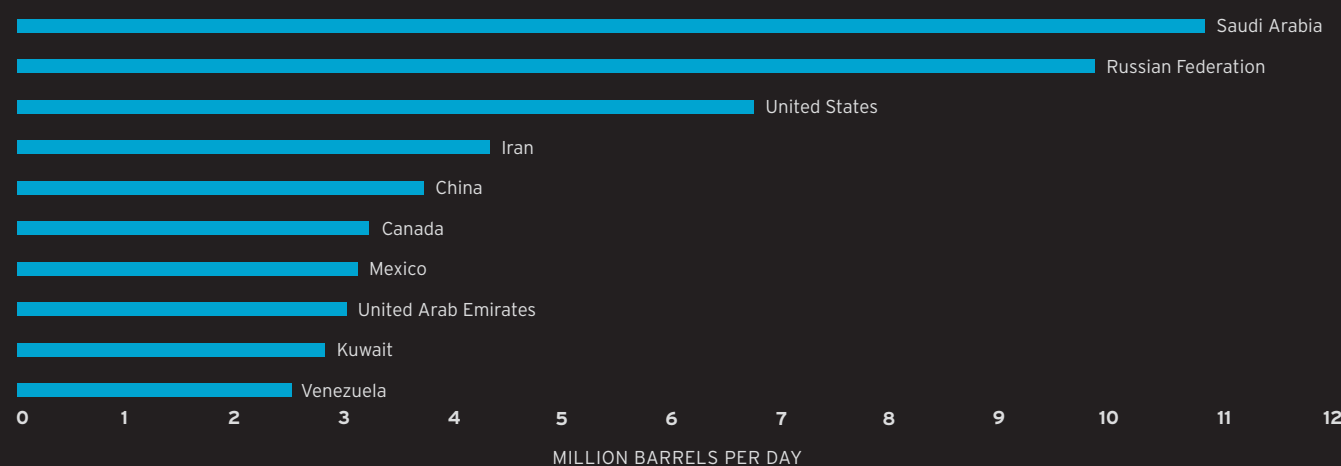
9 DOE, EIA, *Supplemental Tables to the Annual Energy Outlook 2009*, (Table 45), available at www.eia.doe.gov/oiaf/aeo/supplement/supref.html, last accessed October 28, 2009.

10 SAFE calculations based on data from AER 2008.

11 IEA, *World Energy Outlook 2008*, at 93 (Table 3.1).

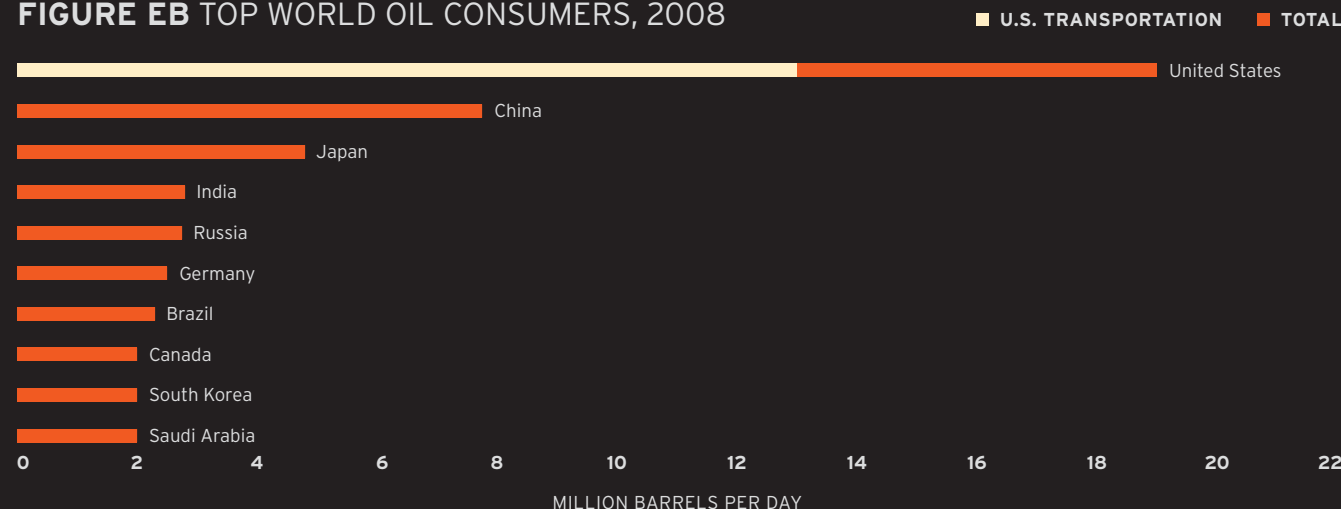
12 DOE, EIA, *World Oil Transit Choke Points*, available at www.eia.doe.gov/cabs/World_Oil_Transit_Chokepoints/Background.html, last accessed October 28, 2009.

FIGURE EA TOP WORLD OIL PRODUCERS, 2008



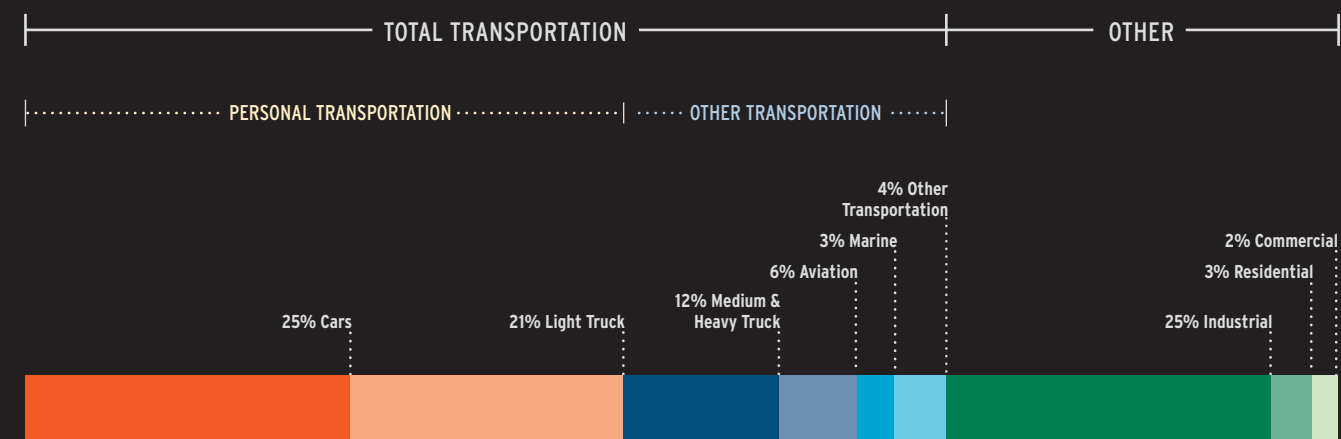
Source: BP, plc

FIGURE EB TOP WORLD OIL CONSUMERS, 2008



Source: BP, plc

FIGURE EC U.S. OIL CONSUMPTION BY TYPE, 2007



Source: DOE, EIA

American military and ultimately the American taxpayer. A 2009 study by the RAND Corporation placed the cost of this defense burden at between \$67.5 billion and \$83 billion annually.¹³

Finally, in addition to these immediate threats to the national interest, petroleum consumption poses a long-term threat to global environmental sustainability. It is important to recognize that curbing emissions is a global issue and that there is not yet an international consensus on a long-term stabilization objective or on the required changes in emissions trajectory to meet such a goal. Nonetheless, international discussions are increasingly centered on a stabilization level that ranges between 450 and 550 parts per million (ppm) CO₂ equivalent (CO₂-eq).¹⁴ Regardless of the exact nature of a final emissions stabilization target, it is clear that nearly any goal will be determined in large part by the extent to which the increase in fossil fuel-related GHG emissions is slowed down or reversed.

Despite the magnitude of the challenge and decades of political and policy shortfalls, a solution to America's oil dependence is emerging. The United States now has the capacity to permanently enhance our national security and safeguard our economy. To do so, however, the United States must fundamentally transform our transportation sector, moving from cars and trucks that depend on costly oil-based fuels to an integrated system that powers our mobility with domestically-generated electricity.

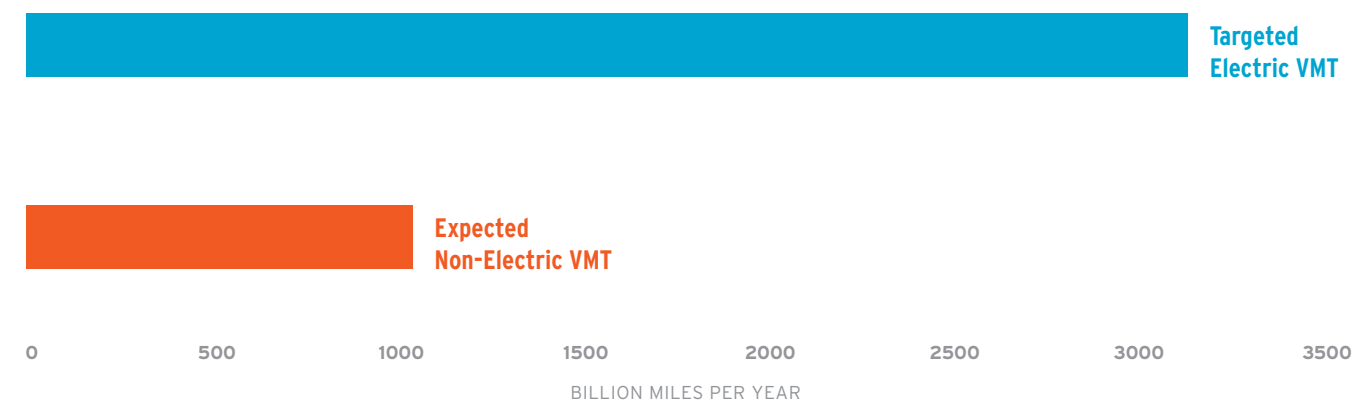
Electrified transportation has clear advantages over the current petroleum-based system. Electricity represents a diverse, domestic, stable, fundamentally scalable energy supply whose fuel inputs are almost completely free of oil. High penetration rates of grid-enabled vehicles—vehicles propelled in whole or in part by electricity drawn from the grid and stored onboard in a battery—could radically minimize the importance of oil to the United States, strengthening our economy, improving national security, and providing much-needed flexibility to our foreign policy. Simultaneously, such a system would clear a path to dramatically reduced economy-wide emissions of greenhouse gases.

Therefore, this report proposes completely transforming the light-duty vehicle fleet into one in which grid-enabled mobility is the new conventional standard. By 2040, 75 percent of the light-duty vehicle miles traveled (VMT) in the United States should be electric miles. As a result, oil consumption in the light-duty fleet would be reduced to just 2.0 mbd, compared to today's level of 8.6 mbd, and it is conceivable that U.S. oil imports could effectively be reduced to zero.

¹³ RAND Corporation, "Imported Oil and U.S. National Security," at 71 (2009).

¹⁴ International Energy Agency, "World Energy Outlook 2008," at 410.

FIGURE ED TARGETED ELECTRIC VEHICLE MILES TRAVELED, 2040



PART ONE THE CASE FOR ELECTRIFICATION

The primary advantages of electrification derive from replacing petroleum fuels in our light-duty vehicles with electricity. Total U.S. oil demand over the five years from 2004 through 2008 averaged 20.4 million barrels per day.¹⁵ Over the same period, oil demand within the aggregate transportation sector averaged 13.9 mbd.¹⁶ Light-duty vehicles—cars, SUVs and motorcycles—accounted for approximately 8.6 mbd of total transportation demand. That is, passenger vehicles currently account for roughly 40 percent of total U.S. petroleum demand. In short, if the United States is to address oil dependence, petroleum use in light-duty vehicles must be sharply reduced.

Electrification would allow the transportation sector to access a number of strategic advantages inherent to the electric power sector:

- › **Electricity is Diverse and Domestic.** Electricity is generated from a diverse set of largely domestic fuels. An electricity-powered transportation system, therefore, is one in which an interruption of the supply of one fuel can be made up for by others.
- › **Electricity Prices are Stable.** Electricity prices are significantly less volatile than oil or gasoline prices. Since 1983, the average retail price of electricity

delivered in the United States has risen by an average of less than 2 percent per year in nominal terms and has actually fallen in real terms.

- › **The Power Sector has Substantial Spare Capacity.** The U.S. electric power sector is constructed to be able to meet peak demand. However, throughout most of a 24-hour day—particularly at night—consumers require significantly less electricity than the system is capable of delivering. Therefore, the U.S. electric power sector has substantial spare capacity that could be used to power electric vehicles.
- › **The Network of Infrastructure Already Exists.** Unlike many proposed alternatives to petroleum-based fuels, the nation already has a ubiquitous network of electricity infrastructure. No doubt, electrification will require the deployment of charging infrastructure, additional functionality, and increased investment in grid reliability, but the power sector’s infrastructural backbone—generation, transmission, and distribution—is already in place.

In order to harness the strategic advantages of the electric power sector in the light-duty vehicle fleet, vehicles that can be propelled by electricity must be available to consumers. In fact, the technology for such

vehicles has advanced rapidly in recent years. Though important challenges remain, the global automotive industry has invested heavily in highly-efficient electric drive vehicles that utilize lithium-ion batteries to store electricity from the grid.

In general, grid-enabled electric drive systems can be either pure electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs). Both EVs and PHEVs store energy from the grid in on-board batteries. Energy from the battery powers a highly-efficient electric motor that propels the vehicle. EVs substitute an electric drivetrain for all conventional drivetrain components. PHEVs retain the use of a down-sized internal combustion engine that supplements battery power.

Both EVs and PHEVs provide consumers and the broader economy with two distinct advantages compared to conventional vehicles:

- › **Electric Miles are Cheaper than Gasoline Miles.** Operating a vehicle on electricity in the United States is considerably less expensive than operating a vehicle on gasoline. In large part, this is due to the high efficiency of electric motors, which can turn 90 percent of the energy content of electricity into mechanical energy. In contrast, today’s best internal combustion (IC) engines have efficiency ratings of just 25 to 27 percent. With gasoline at \$3.00 per gallon, the operating cost of a highly-efficient IC engine vehicle (30 miles per gallon) is 10 cents per mile. For current pure electric vehicles, assuming an average electricity price of 10 cents per kilowatt hour, operating costs are only 2.5 cents per mile.

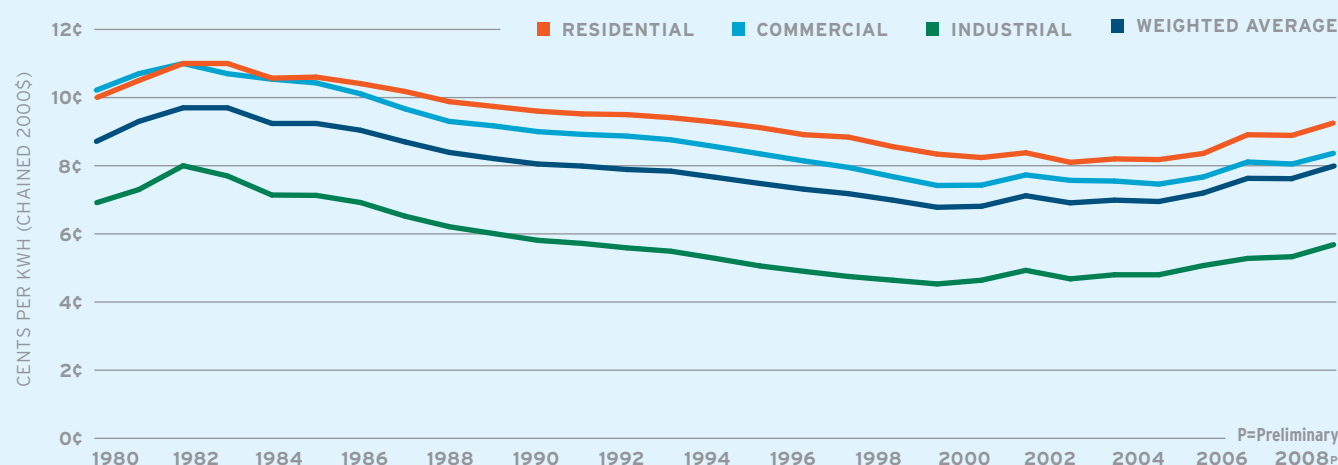
- › **Electric Miles are Cleaner than Gasoline Miles.** Vehicle miles fueled by electricity emit less CO₂ than those fueled by gasoline—even with today’s mix of generating resources. As renewable power increases its share of the electricity portfolio, and to the extent that new nuclear power comes on line, the emissions profile of the U.S. power sector will continue to improve over time; this improvement will directly enhance the emissions benefits of grid-enabled vehicles. This pattern will only accelerate if climate change legislation is enacted and stricter emissions goals are established in the United States. Finally, to the extent that grid-enabled vehicles

(GEVs) are charged overnight using power from baseload nuclear or off-peak renewable resources, their emissions footprint can be nearly eliminated.

Because the vast majority of material in lithium ion batteries is recyclable, the increased use of grid-enabled vehicles does not present the United States with additional resource dependency. Particularly when recycling is assumed, global lithium reserves are adequate to support even the most bullish GEV deployment scenarios. Moreover, at a structural level, dependence on lithium is unlike dependence on oil. Vehicles do not deplete batteries as we drive; they deplete the energy stored within them. In other words, batteries are like the engines in conventional vehicles of today; though their life span is finite, they last for many years. Coupled with the fuel diversity of the electric power sector, grid-enabled vehicles generally insulate consumers from volatile commodity markets.

Finally, current federal policy provides support to a range of fuels designed to displace petroleum as the dominant fuel in the U.S. transportation system. Electrification offers the fuel diversity, price stability, and emissions benefits needed to meaningfully increase U.S. energy security. Instead of scattered, inconsistent federal support for a wide variety of alternatives, what is required is a coherent, focused strategy designed to radically drive down oil consumption in the light-duty fleet. Part of this strategy must be the acknowledgement that other alternatives, while having value, cannot ultimately revolutionize America’s light-duty fleet and end oil dependence.

FIGURE EE AVERAGE RETAIL PRICE OF ELECTRICITY



Source: DOE, EIA

¹⁵ BP Statistical Review 2009, at 12. Note: Includes ethanol.

¹⁶ DOE, AER, Table 5.13c. Note: Includes ethanol.

PART TWO CHALLENGES & OPPORTUNITIES

Despite the rapid progress currently being made in the global electric vehicle market, substantial barriers to widespread vehicle adoption still exist. Overcoming these barriers will require innovative business models and stable, effective public policy. The four principal challenges to electrification of transportation are: 1. Batteries and Vehicles, 2. Charging Infrastructure, 3. Electric Power Sector Interface, and 4. Consumer Acceptance.

BATTERIES AND VEHICLES

No obstacle to GEV adoption has been as formidable as the development of battery technology. In short, batteries have never been able to compete with the tremendous energy density of petroleum fuels. The last several years, however, have seen enormous strides in battery technology, substantially lowering costs and increasing range potential. This progress has enabled the design and manufacture of grid-enabled vehicles that can compete with the performance and convenience of gasoline-powered cars. Improvements in battery performance can be grouped into at least five categories: power, energy, safety, life and cost.

A key catalyst in battery innovation has been the advent of lithium-ion battery technology. First deployed in consumer electronics, today's lithium-ion technology enables very large batteries with long ranges to be placed in vehicles while minimizing the weight and size burden compared to previous technologies.

Factors such as battery life require ongoing testing and research, but the first generation of grid-enabled vehicles powered by lithium-ion batteries will reach U.S. markets in the next 18 months. The largest obstacle to widespread consumer adoption of these vehicles will be cost. Existing policies have already begun to reduce these costs; for example, the American Recovery and Reinvestment Act of 2009 introduced tax credits that range up to \$7,500 for grid-enabled vehicles depending on battery size. However, the greatest reduction in battery prices will come when manufacturers reach scale in production volumes, which for individual facilities is estimated at roughly 100,000 units per year.

The scale that can be achieved in the automotive supply base will, in turn, depend on the demand created by each automaker's electric vehicle development

strategy. A typical vehicle platform is replaced every five to seven years. At that rate, if auto manufacturers were to adopt a plug-in vehicle strategy, but were to roll out grid-enabled vehicles incrementally, it would take a several decades to turn over their product portfolio from predominantly IC engine-based vehicles to GEVs. This approach would ensure a long wait for suppliers throughout the value chain to achieve the scale needed to dramatically reduce cost. Meanwhile, these suppliers would be stranded with the large investments they made to develop products and manufacturing capacity for electric vehicles.

Coalition Recommendations

- › Establish tax credits for installing automotive grade batteries in stationary applications to help drive scale
- › Establish loan guarantees for retooling automotive assembly lines

CHARGING INFRASTRUCTURE

There are different levels of charging based on the power available. Level I charging uses the traditional 110 volt outlet. Though relatively slow, it may be sufficient for many PHEV owners. The longer charges required by larger EV batteries will likely convince many consumers to opt for higher-power Level II charging. Level II charging is specified at between 208 and 240 volts (the voltage used in many homes by clothes driers, ovens, and well pumps).

Most vehicles sit idly overnight at homes, which provides ample opportunity to charge their GEVs. Important shortcomings of home charging will need to be addressed before grid-enabled vehicles can be widely adopted, however. First, many homes will require installation of a 220 volt plug in the garage or parking shelter if they want Level II charging. Of greater concern may be the fact that many households lack access to a dedicated parking space. For them, overnight charging will be more difficult.

While home charging will be important for achieving high rates of GEV deployment, public charging is arguably more important for moving past the very

early stages of GEV adoption. Drivers are accustomed to being able to fill up using the ubiquitous gasoline infrastructure developed over the last 100 years. Inability to do so will generate significant hesitancy—range anxiety—for many drivers, and may reduce the fuel economy of PHEVs. Especially early on, a readily available network of Level II public charging facilities may assist in minimizing range anxiety. It should be supplemented by public Level III chargers capable of providing a high voltage “fast charge” that can charge vehicle batteries in minutes rather than hours. Level III facilities will allow a fast charge for a driver who forgot to or was unable to charge overnight, or who is traveling beyond the range of the vehicle without the time to stop and wait for a slower charge. Level III chargers will also likely need to be deployed along intercity roads to provide charging opportunities for longer trips.

GEV advocates have suggested that private firms should install public charging infrastructure wherever consumers may need it. However, a profitable business model for public charging infrastructure has not been reliably demonstrated. The only way for consumers to recover the cost of an expensive battery is to defray it over time with comparatively cheap electricity. This upper bound on the price consumers are willing to pay to charge their vehicles, and the readily available substitute of home charging, places an upper limit on what consumers will be willing to pay for public charging.

Coalition Recommendations

- › Modify building codes to promote GEV adoption

ELECTRIC POWER SECTOR INTERFACE

GEVs represent an enormous opportunity for the nation's electric utilities and electricity market retailers in both regulated and competitive electricity markets. Light-duty vehicles today are the largest energy consumers in the transportation sector, which is the most significant sector of the economy that relies on some form of energy other than electricity. The nation currently consumes about 4.1 trillion kWh of electric power each year. If 150 million light-duty GEVs each consume 8 kWh of power a day, that would represent an additional 440 billion kWh of power consumed each year.

Depending on the manner in which that power is consumed, there may be relatively little need for additional generating capacity; much of the vehicle

charging can take place during off-peak hours when significant generating capacity is typically idle. Moreover, by flattening the load curve and increasing the utilization rates of existing power generating plants, utilities should be able to spread their fixed costs over a greater volume of power and reduce maintenance costs, perhaps lowering costs for all of their customers.

While adding millions of GEVs as customers is a great opportunity for utilities, it will require them to address several issues. Some utilities will have to upgrade distribution-level transformers to ensure reliable service to homes and other charging locations. Along with investments in smart meters and smart charging software, utilities will need to invest in IT infrastructure to support a range of smart grid applications including GEVs. Further, both utilities and electricity market retailers will need new rate plans to reliably serve GEVs. Regulatory reforms are also required.

Coalition Recommendations

- › Promote the inclusion of GEV-related investment in the utility rate base
- › Adjust utility rate structures to facilitate GEV deployment

CONSUMER ACCEPTANCE

New innovations often require many years to become widely adopted in the marketplace. Making a successful entrance into a competitive automobile market established a century ago is no easy task. Traditional gasoline-electric hybrid vehicles have so far failed to overcome the hurdles, accounting for approximately 3 percent of new vehicle sales in 2008. To a degree, hybrids have demonstrated their potential among early adopters and with automobile manufacturers. However, without a change in consumer attitude, widespread consumer acceptance of electrification remains a difficult proposition. The market for these technologies will only reach a “take-off” point if they can offer a compelling alternative to conventional IC engines on either cost or performance grounds.

Coalition Recommendations

- › Establish a guaranteed residual value for used large-format automotive batteries
- › Review existing regulations on vehicle warranties

PART THREE ANALYSIS OF THE GOAL

This report sets a national goal for electrification. Specifically, by 2040, 75 percent of the vehicle miles traveled in the United States should be electric miles. In order to meet this goal, grid-enabled vehicles will need to make significant inroads into new light-duty vehicle sales between 2010 and 2020 and then expand that share over the following decades. Because vehicles tend to stay on the road for a decade or more, even very high rates of GEV adoption will take time to penetrate the American fleet of 250 million light-duty vehicles.

Expressing a national goal in terms of “electric miles” acknowledges two key issues. First, expressing the goal in terms of market share or sales penetration alone would not necessarily translate directly to an equivalent oil abatement number. That is, reaching the point where 50 percent of all light-duty vehicles were

By 2040, 75% of the vehicle miles traveled in the U.S. should be electric miles.

GEVs would not necessarily reduce LDV oil consumption by 50 percent. This is because different population segments account for varying proportions of total miles traveled. Setting an ambitious VMT target clarifies the notion that GEVs will need to be adopted by all consumer segments, particularly those that account for the highest share of miles traveled.

Second, the transition from a market dominated by IC engine vehicles to one dominated by GEVs will likely incorporate a number of technological solutions within the framework of electric drivetrains. That is, there will surely be an assortment of GEV technologies on the road, including both PHEVs and EVs. An electric mile is any mile in which the vehicle is propelled by an electric motor and not relying on a gasoline engine. Different technologies will have varying ability to maximize electric miles, with pure EVs obviously being the most efficient. Using electric miles as a common measurement, therefore, facilitates the use of a single goal that is applicable over a range of GEVs.

The analysis conducted for this report acknowledges that there will be an evolving mix between PHEVs and EVs. At first, PHEVs achieve a dominant share of total GEV sales, primarily because they present owners with a lower total cost of ownership than pure EVs. Moreover, PHEVs do not have the same range limitations as pure EVs. Over time, as battery costs decline, charging infrastructure is widely deployed, and EV ranges increase, EVs capture the dominant position within the GEV market and the broader light-duty vehicle market as well.

If not managed properly, deploying electric vehicles at this scale could have significant consequences for electricity prices and the reliability of the grid, particularly at the distribution level. Therefore, it will be important to implement public policies that support efforts by utilities to deploy technology, including smart software, to coordinate the vehicle charging process and to include the costs of such equipment in their rate bases. Further, policies that encourage consumers to charge vehicles at night during off-peak hours, while maintaining consumer flexibility, will also be of paramount importance.

Of course, the most substantial obstacle to wide-scale vehicle electrification is the higher cost of grid-enabled vehicles. However, the cost of owning a GEV will come down in the coming years based on the declining costs of batteries, electric motors, power inverters, on-board chargers, and power electronics, among other factors. Analysis presented in this report shows that, based on existing government incentives, PHEVs should already have a lower total cost of ownership than IC engine vehicles. By 2013, total costs of ownership for pure EVs should also be lower than conventional vehicles. By 2020, both EVs and PHEVs offer a value proposition for consumers even without tax credits, and falling battery costs make EVs the best value for most drivers.

FIGURE EF REQUIRED SALES PENETRATION

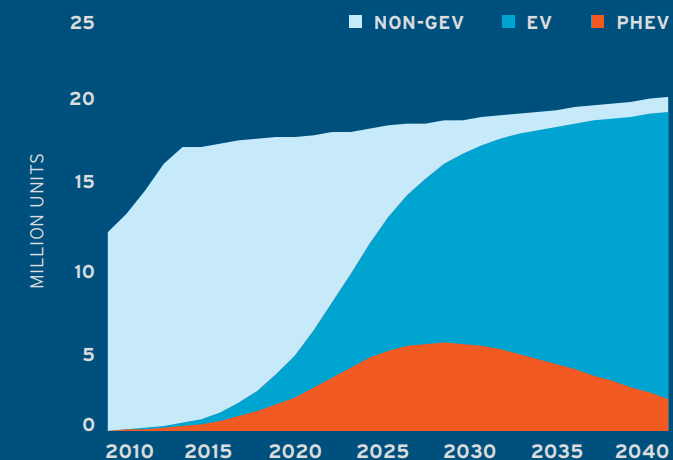


FIGURE EG REQUIRED FLEET PENETRATION

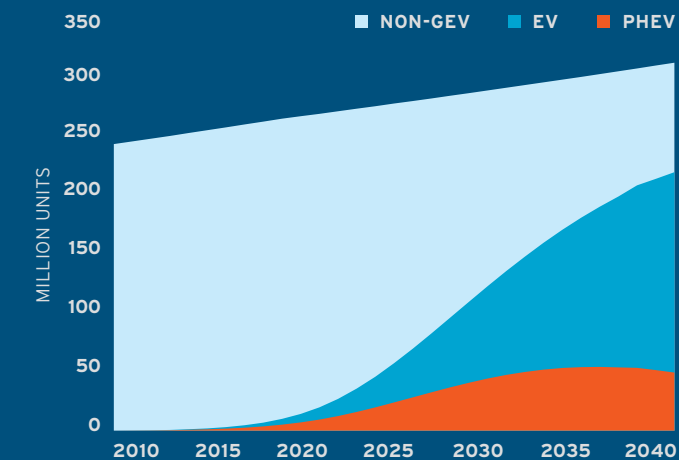


FIGURE EH VEHICLE MILES TRAVELED

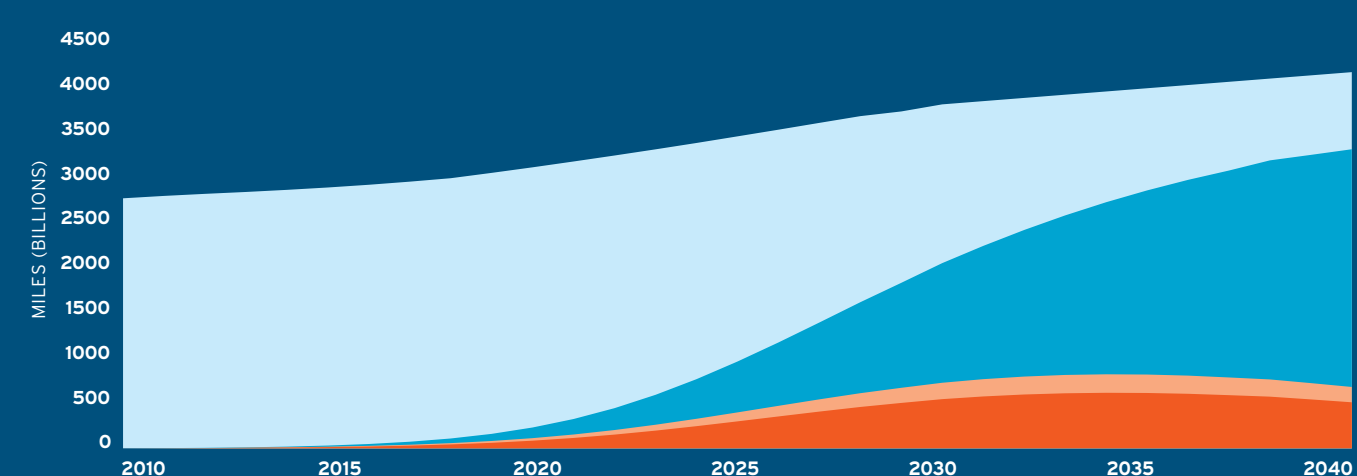
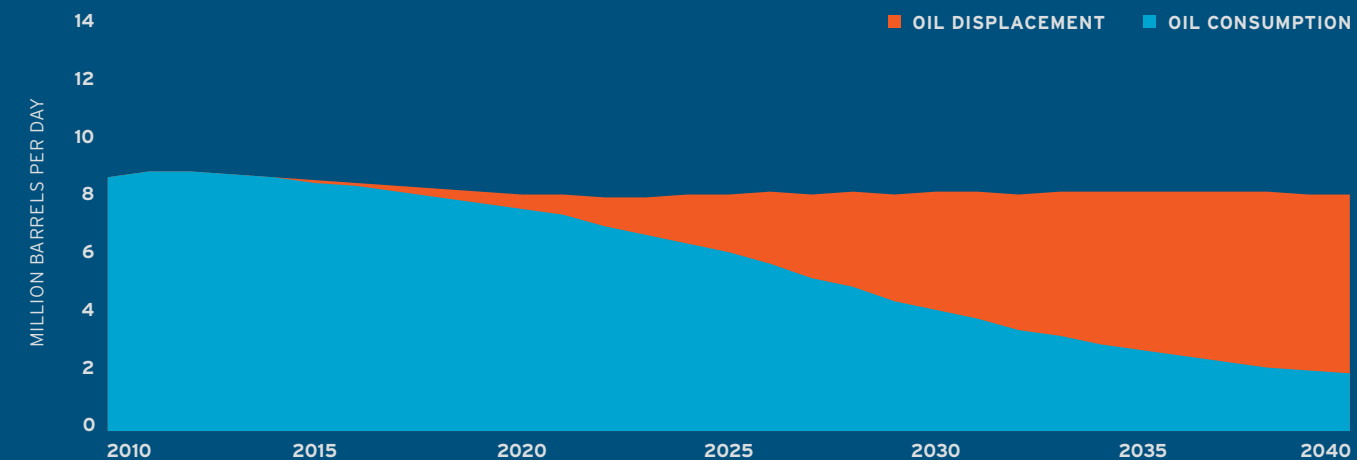


FIGURE EI EXPECTED LIGHT-DUTY VEHICLE OIL ABATEMENT



Source: PRTM Analysis

PART FOUR STRATEGIC DEPLOYMENT

In order to achieve deployment of grid-enabled vehicles at a level consistent with the goals of this roadmap, an ambitious federal initiative to establish electrification ecosystems in a number of American cities will be required. An ecosystem is a group of interdependent entities that work or interact together to accomplish a common task or goal. In the GEV context, an electrification ecosystem is a community in which each of the elements necessary for the successful deployment of grid-enabled vehicles is deployed nearly simultaneously in high concentrations. By ensuring that vehicles, infrastructure, and the full network of support services and technologies arrive in well-defined markets together, ecosystems will provide an invaluable demonstration of the benefits of integrated electrification architecture. Electrification ecosystems will:

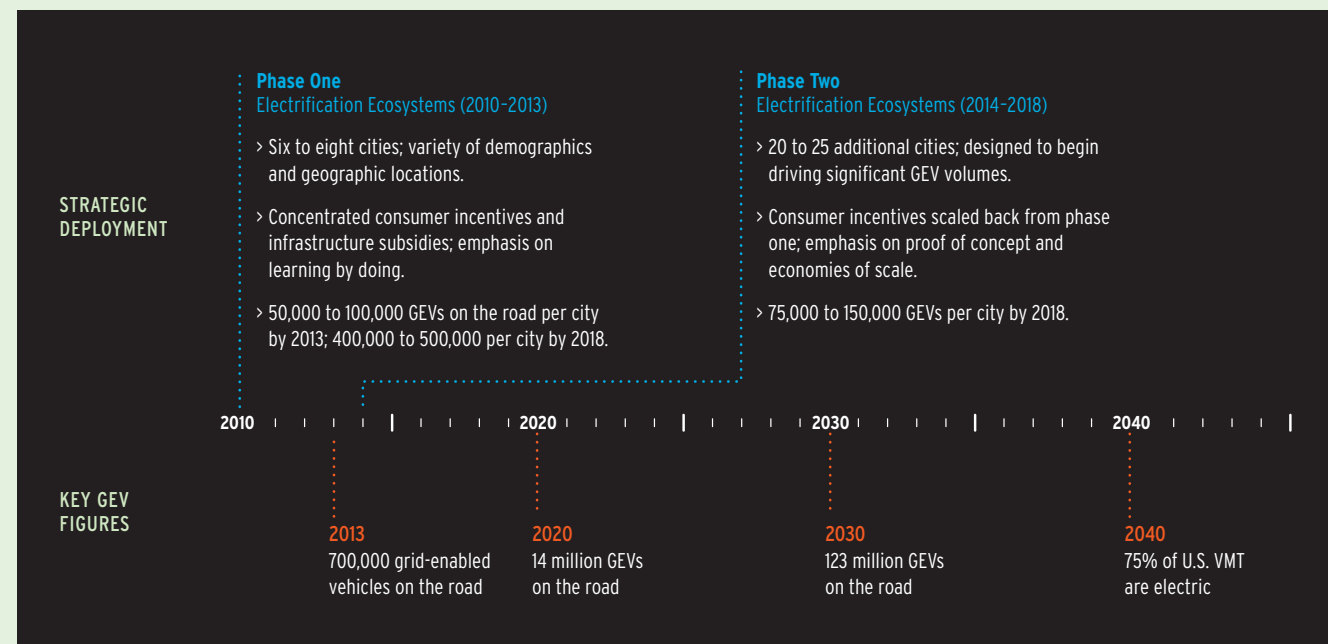
- › **Demonstrate Proof of Concept.** By demonstrating the benefits of grid-enabled vehicles in a real world environment, ecosystems will make consumers aware of the tremendous potential of electrification.

- › **Drive Economies of Scale.** Electrification ecosystems will allow market participants to take advantage of economies of scale, particularly with regard to charging infrastructure. They will also drive demand for grid-enabled vehicles at a rate that is likely to be far in excess of the rate if the vehicles are simply purchased by early adopters scattered around the United States.

- › **Facilitate Learning by Doing.** Electrification ecosystems will play a feedback role in the GEV innovation process. Data aggregation and concentration of efforts will be informative to new innovation.

Ecosystem cities should be chosen on a competitive basis with an application that mirrors the core components of, for example, an International Olympic Committee bid. Successful bids would ideally be submitted by a coalition of entities in a community reflecting wide support for GEV deployment. Such coalitions should reflect the support of: state and local government; the applicable Public Utility Commission; local utilities; large local employers; and others.

FIGURE EJ PHASED DEPLOYMENT



PHASE ONE ECOSYSTEMS

A phased process will maximize the effectiveness of the electrification ecosystem concept. Phase one ecosystems should each reach stock penetration rates of 50,000 to 100,000 vehicles by 2013. This level of deployment would place the nation on a path to deploy approximately 700,000 grid-enabled vehicles on the road by 2013, consistent with the national goal of 75 percent electric VMT by 2040. Moreover, in appropriately sized cities, this will represent a significant portion of newly-purchased vehicles. Massing that many vehicles in a limited number of communities will prove that GEVs can work at scale and allow researchers to generate a large enough data set to evaluate GEV usage patterns.

Phase one of the ecosystem deployment strategy is intended primarily as a proof of concept and data collection exercise. The goal is primarily to take advantage of economies of scale in a handful of cities to deploy relatively large numbers of GEVs in order to build consumer confidence and accelerate the learning process. The lessons learned in those communities will help other cities determine how much charging infrastructure is necessary and where it should go, when drivers will charge their vehicles, how much they are willing to pay to charge their vehicles, to what extent their charging patterns will be affected by the price of electricity, and what business models might be most successful.

Coalition Recommendations

- › Create position of Assistant Secretary for Electric Transportation at the Department of Energy
- › Modify plug-in electric drive vehicle tax credits by significantly increasing them for vehicles purchased and registered in phase one ecosystems
- › Establish tax credits equal to 75 percent of the cost to construct public charging infrastructure in phase one ecosystems
- › Extend consumer tax credits for home charging equipment
- › Establish tax credits equal to 50 percent of the costs of the necessary IT upgrades for utilities or power aggregators to sell power to GEVs in phase one ecosystems

PHASE TWO ECOSYSTEMS

Phase two of the deployment strategy is intended to jumpstart the wide-scale deployment of GEVs to the levels needed to achieve the goals of 14 million GEVs on the road by 2020 and more than 120 million GEVs on the road by 2030. Therefore, phase two will expand deployment to between 20 and 25 additional cities. At the same time, as the GEV concept is proved, battery costs decline, and infrastructure deployment becomes more efficient, government support in ecosystems can also decline.

Phase two ecosystems should each reach stock penetration rates of 75,000 to 150,000 vehicles by 2018. This level of deployment would place the nation on a path to deploy approximately 7 million grid-enabled vehicles on the road by 2018, consistent with the national goals set out in Part One of the roadmap. By the end of phase two, the nation will be on target to reach Milestone One, in which 25 percent of new light-duty vehicle sales are grid-enabled vehicles.

Coalition Recommendations

- › In phase two, adjust consumer tax credits for GEVs and standardize them across phase one and phase two ecosystems
- › In phase two, adjust tax credits for public charging infrastructure to approximately 50 percent of the cost
- › In phase two, adjust financial support to 20 percent of the cost for IT upgrades for utilities or power aggregators to sell power to GEVs

PART ONE

The Case for Electrification



1.1 OVERVIEW



1.2 THE PROBLEM



1.3 THE SOLUTION



1.4 THE TARGET



1.5 NATIONAL IMPERATIVE



1.6 ELECTRIFICATION POLICY



A soldier keeps watch from a checkpoint in Iraq.

ABSTRACT

The Case for Electrification

The United States is dangerously exposed to a global oil market whose fundamental characteristics all but guarantee increasing volatility and instability. Oil dependence weakens our national security, threatens our economy, and degrades the environment. U.S. oil dependence stems largely from the transportation sector, which relies on petroleum for 94 percent of its delivered energy.

Electrification of transportation—powering our light-duty fleet with electricity—is the best solution available for reducing U.S. oil dependence. Electricity is produced from a diverse range of fuels that are overwhelmingly domestic, and oil has virtually no role in power generation. Today’s generation mix already offers environmental advantages versus conventional combustion engines for transportation, and the increased deployment of renewable generation will only improve this benefit. Finally, the technology to power vehicles with electricity over ranges that meet most drivers’ needs is essentially available today.

1.1 Overview



Modern American life is premised on the assumption that inexpensive oil will always be available to fuel our transportation system. Our vehicles, our jobs, and even the structure of our communities all depend on reliable supplies of affordable oil. Yet growing worldwide demand for oil and tightening supplies strongly suggest that the days of cheap, plentiful oil are over.

Each day, Americans consume nearly 20 million barrels of petroleum—equal to one-fourth of total global oil demand.

In an era of high and volatile oil prices, this level of consumption is extremely costly, both for the economy and the broader national interest. U.S. oil consumption is increasingly a significant driving force behind the nation’s trade imbalances, and erratic oil price movements have contributed to an uncertain business and investment climate for a number of industries, including the automotive sector.

After 150 years of investment and development, the world has probably reached the end of “easy oil.” Today, the U.S. economy is dangerously exposed to a global oil market whose fundamental characteristics will ensure that, at least through the medium term, it is likely to be increasingly volatile and unstable. Growing demand for oil from the developing world, limited access to the reserves owned by national oil companies, and the higher cost of production of those fields that are available to international oil companies all suggest that the threat posed to our economy by our dependence on oil will continue to grow over time.

Oil dependence undermines national security and the conduct of foreign policy by limiting U.S. strategic flexibility, strengthening foreign adversaries, and exacerbating geopolitical competition for resources. It also imposes significant burdens on U.S. armed forces, which must expend enormous military resources protecting the chronically vulnerable global oil production and distribution network while striving to guarantee international access to key oil-producing regions.

Working within the traditional paradigms, though useful on a limited scale, cannot and will not offer the transformative change required to end our nation’s

dependence on petroleum. What is required is a new model. That model should be electrification of our nation’s short-haul ground transportation system.

Electrification offers numerous advantages over the status quo: using electricity promotes fuel diversity; electricity is generated from a domestic portfolio of fuels; electricity prices are less volatile than oil and gasoline prices; using electricity is more efficient and has a better emissions profile than gasoline; using electricity will facilitate reduction of greenhouse gas emissions; and electricity is a low-cost alternative. Moreover, while there is a place in our economy for all fuels, including biofuels, natural gas, hydrogen, and other alternatives, electricity is superior to other practical alternatives to petroleum.

Accordingly, the government should implement policies to actively promote the development and deployment of technology to electrify the light-duty transportation system as part of an effort to reduce the economy’s petroleum intensity.

Last year, President Obama established a goal of getting 1 million GEVs onto the road by 2015. His administration has invested substantial funds from the American Reinvestment and Recovery Act in pursuit of that goal. That investment alone, however, is insufficient to meet the president’s goal. This Roadmap sets a more ambitious target for electrification that will not only meet the president’s goal, but achieve the greater goal of ensuring that by 2040, 75 percent of the light-duty vehicle miles traveled (VMT) in the United States will be electric miles. As a result, oil consumption in the light duty fleet would be reduced to just 2.0 mbd, compared to today’s level of 8.6 mbd. This represents a significant reduction in U.S. oil dependence, and would meaningfully enhance American economic, environmental, and national security.

1.2 The Problem



The U.S. economy is heavily dependent on oil, particularly in our massive transportation sector. Oil price volatility, primarily driven by geopolitical events beyond our control, has made our current level of consumption unsustainable.

A NATION AT RISK

The United States is the world's largest consumer of crude oil and petroleum products, accounting for nearly 25 percent of daily global oil demand.¹ Approximately 40 percent of U.S. primary energy needs are met by oil, giving it a degree of economic significance unmatched by any other fuel.² In 2008 alone, American businesses and consumers spent more than \$900 billion on gasoline, diesel and other refined petroleum products.³ This staggering expenditure represented 6.4 percent of the nation's total gross domestic product.⁴

¹ BP Statistical Review 2009, at.12.

² Id. at 40.

³ AER 2008, at 77 (Table 3.5).

⁴ United States Bureau of Economic Analysis, National Economic Accounts, Current and Real Dollar GDP; AER 2008, at 77 (Table 3.5).



A motorist refuels at one of more than 150,000 gasoline stations in the U.S.

Simply stated, our current way of life is utterly dependent on petroleum. Oil makes possible the flexibility and mobility that define our culture and our economy. In 2008, Americans consumed a total of 7.1 billion barrels of petroleum. Seventy percent of that total—nearly 5 billion barrels of oil—was used in the transportation sector.⁵ Our cars, trucks, planes, and ships depend on petroleum for energy, and there are currently no substitutes deployed at scale. Approximately 94 percent of delivered energy in the U.S. transportation sector is derived from oil.⁶

If the purchase and consumption of petroleum were largely benign, American oil dependence would be of little strategic importance. However, it has become increasingly clear that our consumption of oil is encumbered with substantial costs, both tangible and intangible. For at least 35 years, Americans and our leaders have known that our addiction to oil weakens our national security and inflicts considerable damage on the economy. More recently, scientific consensus suggests that the environmental costs of oil consumption are also large and growing.

⁵ AER 2008, (Tables 5.1 and 5.13c).

⁶ AEO 2009, (Table A.7).



1.2.1 A Decade of Instability and Rising Oil Prices

Since 2003, rising oil demand in emerging markets, slow expansion of global production capacity, and persistent geopolitical volatility have combined to generate significant oil price volatility.

Global oil production is increasingly concentrated in the hands of a small number of nations, many of which are hostile to U.S. interests and afflicted by some combination of extreme poverty, rampant corruption, and political instability. Because there is a single global market for oil, these localized factors can have a large impact on the price of oil paid by all consumers. Oil is a fungible, global commodity, and a change in supply or demand anywhere generally affects prices everywhere.

In recent decades, oil price spikes were most often the result of sudden changes in oil supply based on geopolitical crises. For example, between 1978 and 1980, Iranian oil production fell by 72 percent from 5.3 million barrels per day (mbd) to 1.5 mbd as the Iranian Revolution and subsequent war with Iraq decimated the domestic oil industry. Though these types of price spikes could inflict significant global economic damage, they were also temporary.

More recently, however, high and volatile oil prices have been the result of factors that should be considered structural as opposed to transitory. Economic growth in developing countries like China and India

has added a new component to the world oil demand picture. In total, world demand for oil increased by 11 percent between 2000 and 2008, but fully 100 percent of this growth occurred in developing nations.⁷ In 2004 alone, Chinese oil demand increased by 16.7 percent, a striking indicator of rapid economic expansion.⁸

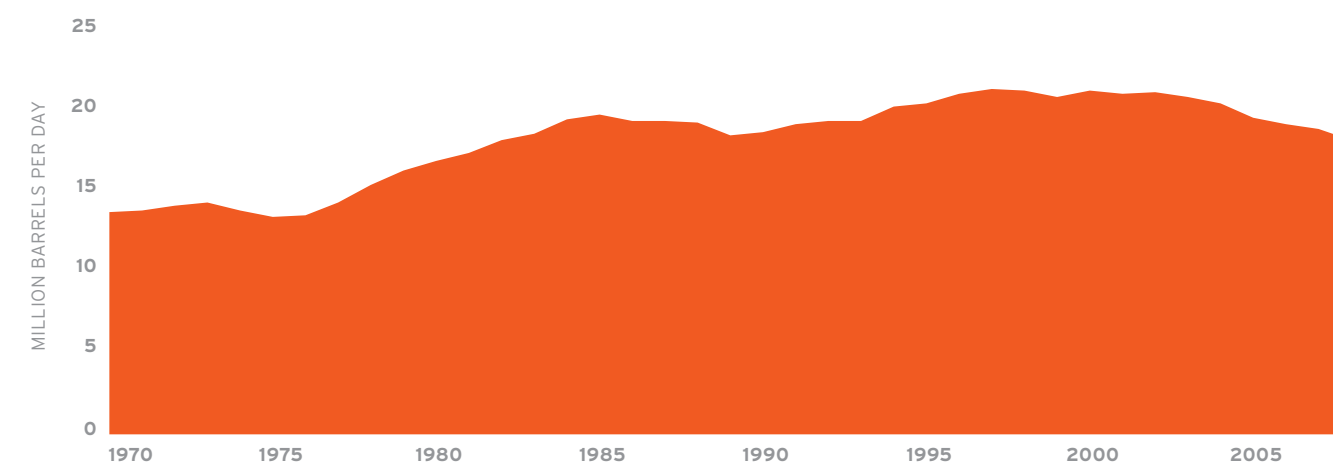
At the same time that global oil demand has been rapidly increasing, oil producers have struggled to keep pace. Output in the world's most developed nations—the 30 members of the Organization for Economic Cooperation and Development (OECD)—reached a plateau in 1997 and markedly decreased each year after 2002. The most promising, cost-effective resources in countries like the United States, Norway, and the United Kingdom were developed aggressively throughout the 20th century, and new projects have thus far only served to slow the rate of overall decline.

With stable oil supplies on the decline, the world has increasingly been dependent on a limited number of volatile sources to deliver growth in conventional oil output. In particular, oil consumers have bet heavily

⁷ BP Statistical Review 2009, at 11.

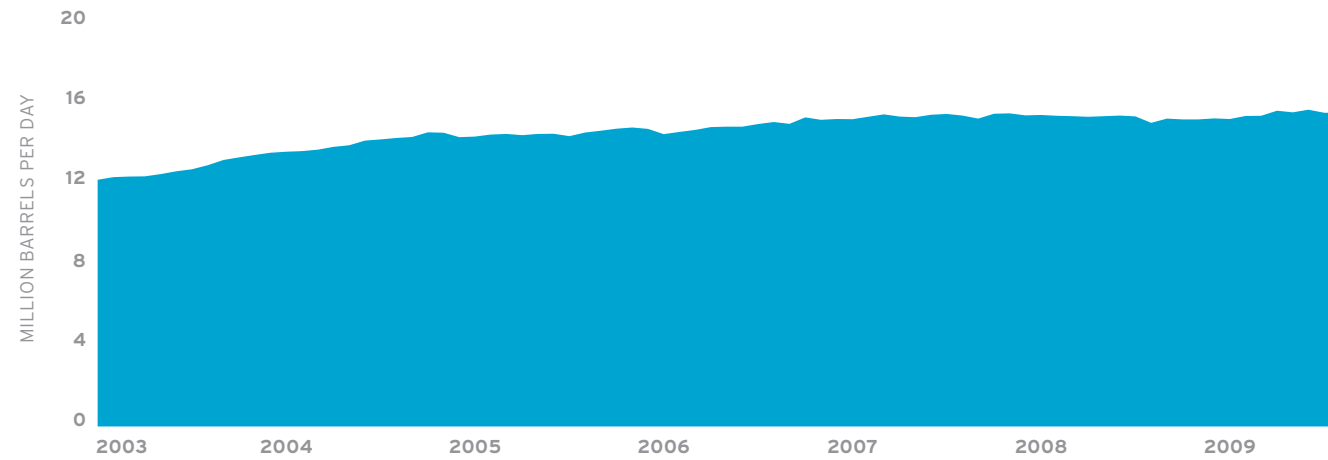
⁸ Id.

FIGURE 1A OECD Oil Production



Source: BP, plc

FIGURE 1B FSU/AFRICA OIL PRODUCTION



Source: BP, plc

on the ability of the Organization of the Petroleum Exporting Countries (OPEC) to expand its production capacity. Together, the 12 OPEC nations control 40 percent of daily oil supplies and hold 76 percent of conventional oil reserves.⁹ The group acts as a cartel, colluding to set production levels in an effort to achieve predetermined price targets.

To be sure, OPEC has abundant, relatively low-cost resources that could be developed. But both the willingness and ability of OPEC to expand production capacity have long been in question. Optimists note that in late 2009, Saudi Arabia completed a five-year, \$100 billion program to expand capacity from 10 mbd to 12.5 mbd, a record level. At the same time, however, capacity in Nigeria and Venezuela fell due to domestic political factors, partially offsetting the Saudi gains.¹⁰ These problems are not new, and based on historical precedent they are likely to persist. In fact, decades of underinvestment left total OPEC production capacity in 2008 at 34 mbd, slightly less than its 37 mbd level 35 years earlier in 1973.¹¹

Regions outside of the OECD and OPEC have also struggled to expand oil production capacity, but for different reasons. States in the former Soviet Union and Africa have become important players in the global oil market. Large oil discoveries have been

made in recent years, by far the largest of which is the 30 billion barrel Kashagan oil field in Kazakhstan.¹² Despite strong growth at the beginning of the decade, however, a range of economic and geopolitical factors has limited the scope of oil production growth in these countries since 2004.

As a result of these factors—rising demand in emerging markets and the inability of suppliers to meaningfully expand production capacity—the global oil market operated on thin margins throughout the period from 2003 to 2008. Spare capacity—OPEC’s surplus production capacity—began the decade at more than 5 million barrels per day, 6.5 percent of daily demand.¹³ By mid-2008, spare capacity had dwindled to 1 million barrels per day, only slightly more than 1 percent of daily demand.¹⁴

In such an environment, even small perturbations can cause massive price swings. A hurricane in the Gulf of Mexico, violence in the Niger Delta, or an oil worker strike in Venezuela can lead to sudden and potentially calamitous swings in the price of oil as markets adjust their expectations about the supply-demand balance and risks to future deliveries of crude oil. This market tightness combined with a period of heightened global instability drove oil prices steadily, almost relentlessly higher for nearly a decade. In 2003, real oil prices

9 Id. at 6, 9.

10 Carola Hoyos, “Saudis Wield Influence with Expansion,” *Financial Times*, September 6, 2009.

11 M.A. Adelman, “Prospects for OPEC Capacity,” *Energy Policy*, Vol. 23, No. 3, p. 235-241 (1995); International Energy Agency, “Medium-Term Oil Market Report,” at 58 (June, 2009).

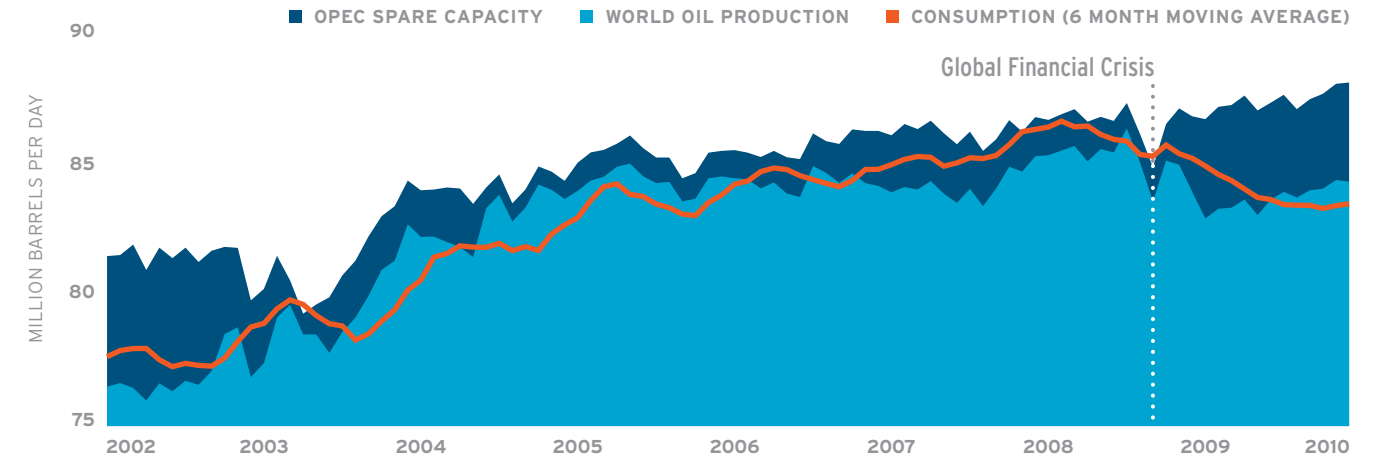
12 Offshore-technology.com, “Kashagan, Caspian Sea, Kazakhstan,” available at www.offshore-technology.com/projects/kashagan/, last accessed on October 22, 2009.

13 DOE, EIA, Short Term Energy Outlook, October 2009; BP Statistical Review of World Energy 2009.

14 Id.; DOE, EIA, Short Term Energy Outlook, October 2009.



FIGURE 1C WORLD OIL PRODUCTION CAPACITY VS. DEMAND



Source: Energy Information Administration

averaged \$33.75 per barrel. The annual average price per barrel rose every year afterward, reaching \$75.14 in 2007 and \$97.26 in 2008.¹⁵

By July 2008, oil prices reached a level that was simply unsustainable throughout the global economy—the point of demand destruction. In general, oil consumption is highly inelastic, but only to a point. As oil topped \$147 per barrel, consumer spending began to fall, business activity slowed, and the global economy was shocked to a stall.¹⁶ Around the world, growth in oil demand quickly subsided, and in many nations it retracted. In the third quarter of 2008, oil consumption in the United States declined more than 8.5 percent compared to the same period in 2007, the largest annual decline since 1980.¹⁷ As a result of falling demand throughout late 2008 and early 2009, OPEC spare capacity was temporarily inflated to its current level of nearly 4 mbd.¹⁸

Yet, despite the current economic environment, the underlying factors that led to record oil prices in 2008 have not substantially changed. Demand growth for oil products—particularly in the industrialized world—has temporarily subsided, to be sure.¹⁹ But this reduction is not the result of any fundamental change in technology, policy, or infrastructure. Rather, it is simply the result of reduced economic activity during the current downturn. As economic activity resumes, demand for all energy—including petroleum—will also increase, particularly in emerging economies that will continue to require high rates of economic growth to accommodate population growth. Assuming no changes in government policies, by 2030 the International Energy Agency (IEA) expects that world demand for petroleum will increase by 21.2 mbd, or roughly 25 percent compared to 2007 levels.²⁰ Of this growth, fully 100 percent is forecast to occur in the developing world, with 63 percent expected in China and India alone.²¹

15 BP Statistical Review 2009.

16 See, e.g., Jad Mouawad, “Gas Prices Soar, Posing a Threat to Family Budget,” *New York Times* (Feb. 27, 2008); Rock Newman, “The Repercussions of \$4 Gas,” *usnews.com* (March 7, 2008) available online at www.usnews.com/blogs/flowchart/2008/03/07/the-repercussions-of-4-gas.html, last accessed on August 25, 2009; Richard S. Chang, “Fueling 1,000 Stories,” *newyorktimes.com* (June 27, 2008) available online at wheels.blogs.nytimes.com/2008/06/27/fueling-1000-stories/?scp=30&sq=gas%20prices%20%244%20budget&st=cse, last accessed on August 25, 2009; John Branch, “At Small Tracks, High Fuel Prices Put Racers in a Pinch,” *New York Times* (June 3, 2008).

17 DOE, EIA, Petroleum Navigator, “U.S. Product Supplied of Crude Oil and Petroleum Products (Thousand Barrels per Day),” available online at tonto.eia.doe.gov/dnav/pet/hist/mttupus2m.htm, last accessed on August 25, 2009.

18 DOE, EIA, Short Term Energy Outlook 2009, Custom Table Builder.

19 AER 2008 at 152-57 (Figures 5.13a & 5.13b and Tables 5.13a, 5.13b, 5.13c & 5.13d).

20 International Monetary Fund, *World Economic Outlook* at 93 (Table 3.1) (2008) (hereinafter WEO 2008).

21 Id. at 97 (Figure 3.5).

1.2.2 No Free Market Solution

Today's global oil market is far removed from the free-market ideal. Resource nationalism in key oil-producing regions of the world has stunted investment and stalled supply growth.

Oil prices may be a function of the laws of supply and demand, but oil markets do not operate freely. At least 78 percent—and by some estimates as much as 90 percent—of global oil and gas reserves are held by national oil companies (NOCs) that are either fully or partially controlled by foreign governments. NOCs often do not have the same incentives as profit-maximizing firms.²² While a handful of NOCs operate like private firms at the technological frontier of the industry, many function essentially as a branch of the central government, depositing oil revenues in the treasury from which they are often diverted to social programs instead of being reinvested in new

projects.²³ This process stunts expansion in production capacity in favor of domestic spending.

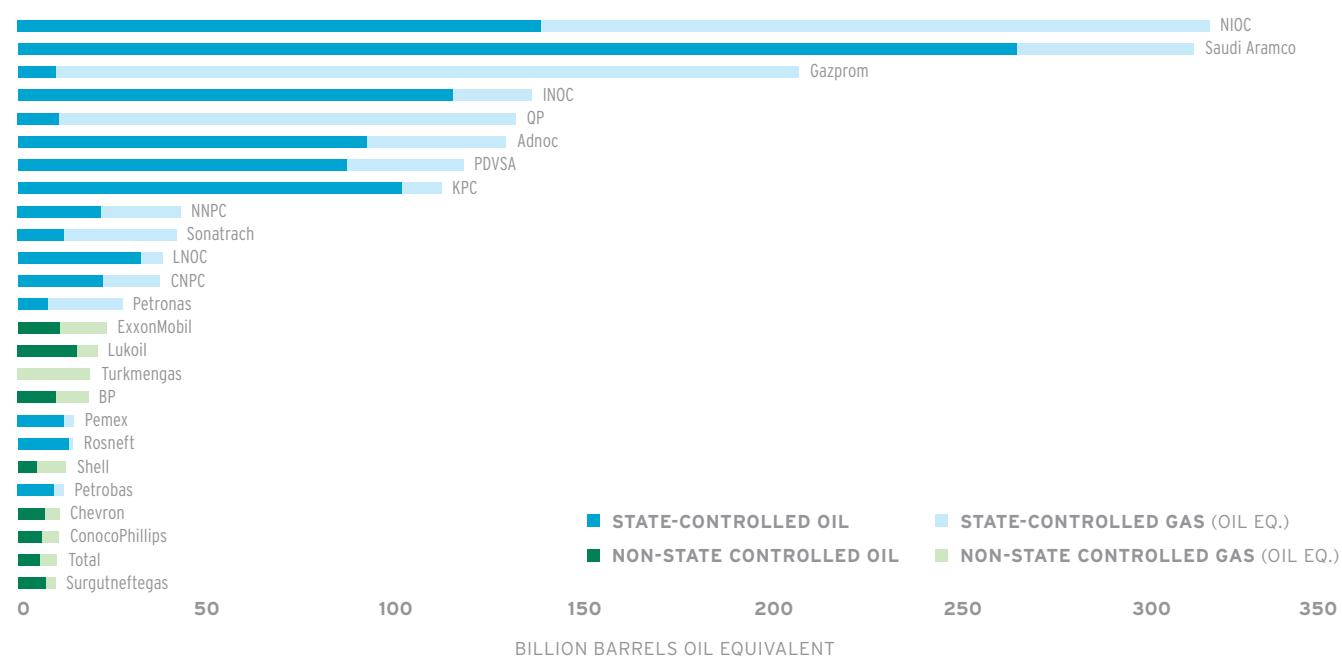
As a result of their reserve dominance, NOCs will increasingly determine the fate of world oil production. In order to meet expected demand growth, the International Energy Agency now forecasts that nearly all the growth in future oil supplies will need to come from NOCs, both within OPEC and beyond. By 2030, well over 60 percent of global oil supplies are forecast to originate with NOCs, but only if adequate investments are made in expanding production capacity.²⁴ More likely, the status quo trend of constrained supply growth is likely to continue over the long term.

Meanwhile, the fraction of global oil reserves that is accessible to international oil companies (IOCs) is

²² Energy Information Administration, *Energy in Brief, Who Are The Major Players Supplying the World Oil Market?*, available online at tonto.eia.doe.gov/energy_in_brief/world_oil_market.cfm, last accessed on October 22, 2009.

²³ Valerie Marcel, "States of Play," *Foreign Policy* (Sept/Oct 2009).
²⁴ WEO 2008.

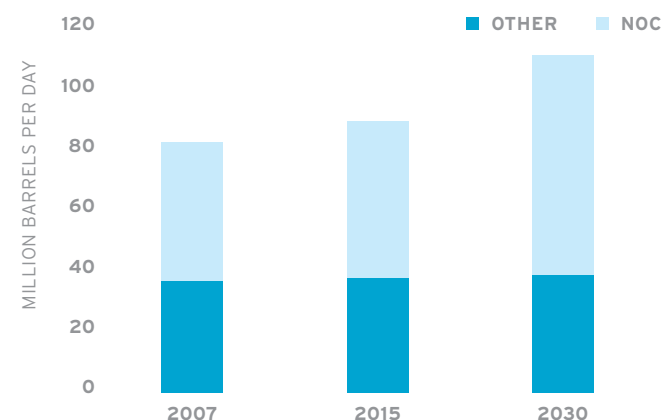
FIGURE 1D PROVED OIL AND NATURAL GAS RESERVES



Source: International Energy Agency



FIGURE 1E WORLD OIL PRODUCTION BY TYPE OF COMPANY



Source: International Energy Agency

growing increasingly complex and costly to produce.²⁵ In addition to the typical costs for pipelines, tankers, and refineries, IOCs must now invest significant additional capital per barrel of oil produced for specialized drilling equipment, oversized offshore platforms, and advanced upgrading facilities. As a result, the marginal cost of production for a barrel of non-OPEC oil has increased rapidly in recent years.²⁶ Currently, the break-even price for Canadian oil sands is estimated at between \$50 and \$80 per barrel.²⁷ For projects in the Gulf of Mexico, marginal costs are estimated to be \$60 per barrel.²⁸ Promising basins off the coast of Brazil and in the North Caspian near Kazakhstan are even more complex and costly.²⁹

With these factors in mind, a strong case can be made that relatively high oil prices are here to stay. Political instability, resource nationalism, and geological challenges will likely continue to constrain oil supply growth for the foreseeable future. Moreover, the recent economic recession—partially triggered by high oil prices—has compounded the problem.

²⁵ WEO 2008, at 343-53 (2008); Bernstein Research, "Global Integrated Oils: Breaking Down the Cost Curves of the Majors, and Developing a Global Cost Curve for 2008," at 14 - 34 (Feb. 2, 2009).

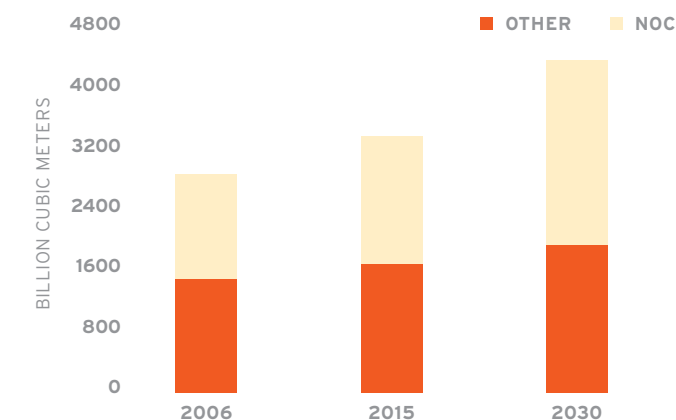
²⁶ Id. at 34.

²⁷ Jeffrey Jones, "UPDATE 1-Suncor CEO Says Oil Sands Profitable at \$50 Crude," Reuters, (April 1, 2009) available online at www.reuters.com/article/mnaNewsEnergy/idUSN0133604420090401, last accessed on August 29, 2009.

²⁸ Energy Information Administration, "Performance Profiles of Major Energy Producers 2007," at 26 (December 2008), online at www.eia.doe.gov/emeu/perfpro/020607.pdf, last accessed on August 28, 2009.

²⁹ See, e.g., Bernstein Research, "Global Integrated Oils: Kashagan - Better Late Than Never - Our Annual Update & Implications For The Owners," (October 1, 2008).

FIGURE 1F WORLD GAS PRODUCTION BY TYPE OF COMPANY



Falling oil prices in late 2008 led to widespread investment deferrals, and it remains to be seen what effect they will have on global production capacity over the medium term.³⁰ In its 2009 Medium Term Oil Market Report, the International Energy Agency forecast that a strong economic recovery would bring the return of reduced levels of spare capacity and a tight oil market by 2014. Other analysts expect the supply crunch to come as soon as 2011.³¹ Regardless of the precise timing, most agree that the clock is ticking.

It remains, however, impossible to forecast with absolute certainty that oil prices will remain high. Advances in technology and ambitious upstream investment programs could keep oil prices closer to their long-run average. More likely, prices could continue to follow a pattern of high volatility—sharp spikes followed by periods of relative calm, consistent with their historical irregularity. In such a scenario, progress in developing alternative fuels and technologies would remain stunted, and the United States could be weakened by petroleum dependence well into the future. It is, therefore, critically important to recognize that even without the expectation of higher oil prices, the costs of U.S. oil dependence have become far too high to sustain. The true cost of oil is largely unrepresented in the price of a barrel on the world market or in the price of a gallon of gasoline at the pump. The external costs of oil dependence are far higher than the prices we pay every day.

³⁰ IEA, "Impact of the Financial and Economic Crisis on Global Energy Investment," at 3 (Background paper for the G8 Energy Ministerial Meeting, Rome, Italy, 24-25 May 2009).

³¹ Macquarie Research (September 2009).

1.2.3 National Security Costs of Oil Dependence

Oil dependence undermines American foreign policy goals when dealing with oil-producing countries. In addition, the burden of securing the global free flow of oil severely burdens the U.S. military.

The importance of oil in the U.S. economy has given it a place of prominence in foreign and military policy. In particular, two key issues related to oil affect national security. First, the vulnerability of global oil supply lines and infrastructure has driven the United States to accept the burden of securing the world's oil supply. Second, the importance of large individual oil producers constrains U.S. foreign policy options when dealing with problems in these nations.

A crippling disruption to global oil supplies ranks among the most immediate threats to the United States today. A prolonged interruption due to war in the Middle East or the closure of a key oil transit route would lead to severe economic dislocation. U.S. leaders have recognized this for decades, and have made it a matter of stated policy that the United States will protect the free flow of oil with military force.³² Still,

³² RAND Corporation, "Imported Oil and U.S. National Security," at 60-62 (2009).



U.S. Marines from the 1st Marine Division get set to deploy into a blocking position April 8, 2003 near a Iraqi Army compound under attack 6-8 miles south east of Baghdad, Iraq.

policy alone has consistently fallen short of complete deterrence, and the risk of oil supply interruptions has persisted for nearly 40 years.

To mitigate this risk, U.S. armed forces expend enormous resources protecting chronically vulnerable infrastructure in hostile corners of the globe and patrolling oil transit routes. This engagement benefits all nations, but comes primarily at the expense of the American military and ultimately the American taxpayer. A 2009 study by the RAND Corporation placed the ongoing cost of this burden at between \$67.5 billion and \$83 billion annually, plus an additional \$8 billion in military operations.³³ In proportional terms, these costs suggest that between 12 and 15 percent of the current defense budget is devoted to guaranteeing the free flow of oil.

Foreign policy constraints related to oil dependence are less quantifiable, but no less damaging. Whether dealing with uranium enrichment in Iran, a hostile regime in Venezuela, or an increasingly assertive Russia, American diplomacy is distorted by our need to minimize disruptions to the flow of oil. Perhaps more frustrating, the importance of oil to the broader global economy has made it nearly impossible for the United States to build international consensus on a wide range of foreign policy and humanitarian issues.

³³ Id. at 71.



1.2.4 Economic Costs of Oil Dependence

The U.S. trade deficit in crude oil and refined products reached \$388 billion in 2008—56 percent of the total trade deficit. Moreover, every recession since 1970 has been preceded by an oil price spike.

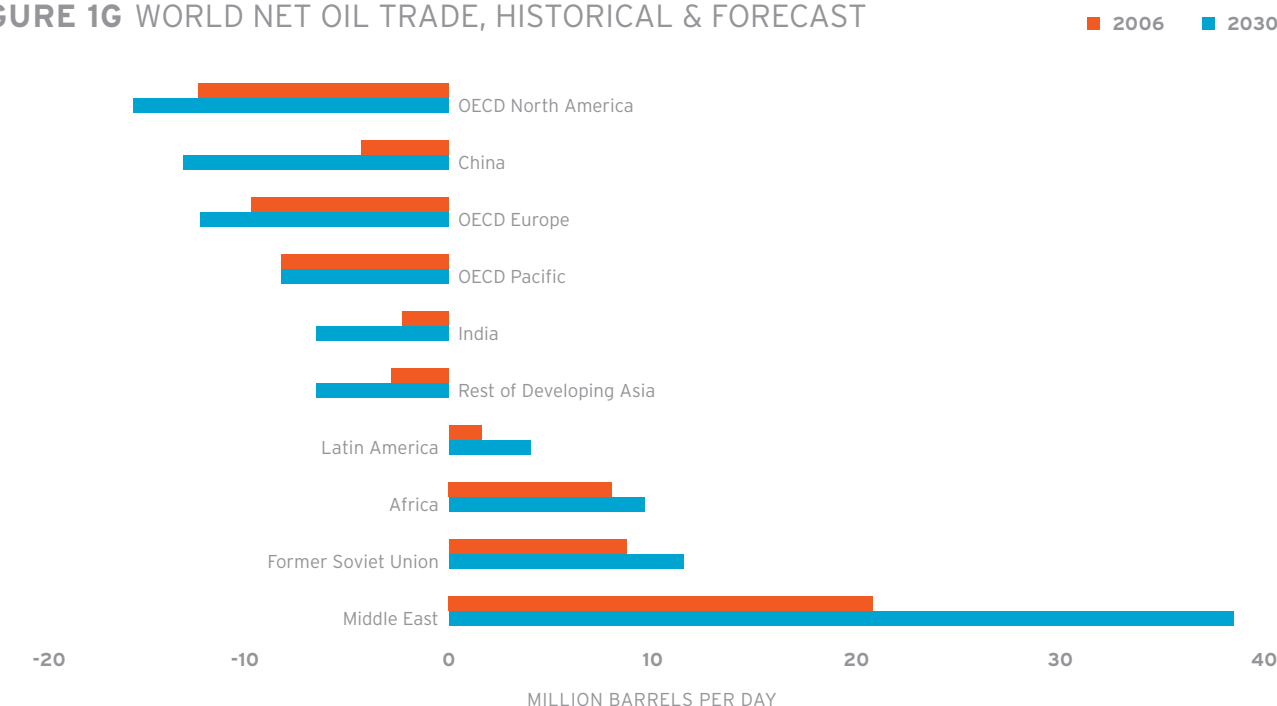
In a past era, the American oil industry dominated the global oil landscape. We imported little if any oil, and prices rose and fell based on production in Texas. No more. Today, although the United States remains the third largest producer of petroleum in the world, U.S. oil production has fallen dramatically from its peak in 1970 as the size of new discoveries has fallen and the productivity of new wells has declined.³⁴ America now imports 58 percent of the oil it consumes, at tremendous cost to the current account balance. In 2007, the U.S. trade deficit in crude oil and petroleum products was \$295 billion.³⁵ In 2008, as oil prices reached all-time highs, that figure increased to \$388 billion—56 percent of the total trade deficit—and U.S. consumers were left with no alternative but to pay the price.³⁶

³⁴ AER 2008 (Tables 5.1 and 5.2).
³⁵ Id., (Table 3.9).
³⁶ Id.

This unprecedented transfer of wealth is of course closely related to national security. With oil prices averaging nearly \$100 per barrel, OPEC earned a record \$971 billion in net oil export revenues in 2008, a 42 percent increase from 2007. Saudi Arabia earned the largest share of these earnings, \$288 billion, representing 30 percent of total OPEC revenues.³⁷ Based on September 2009 oil price projections, the Department of Energy (DOE) forecast OPEC net export revenues to be \$559 billion in 2009 and \$675 billion in 2010.³⁸ Looking forward, OPEC is expected to provide more than half of the world's oil supplies by 2030, significantly increasing the net oil trade surplus in the Middle East.

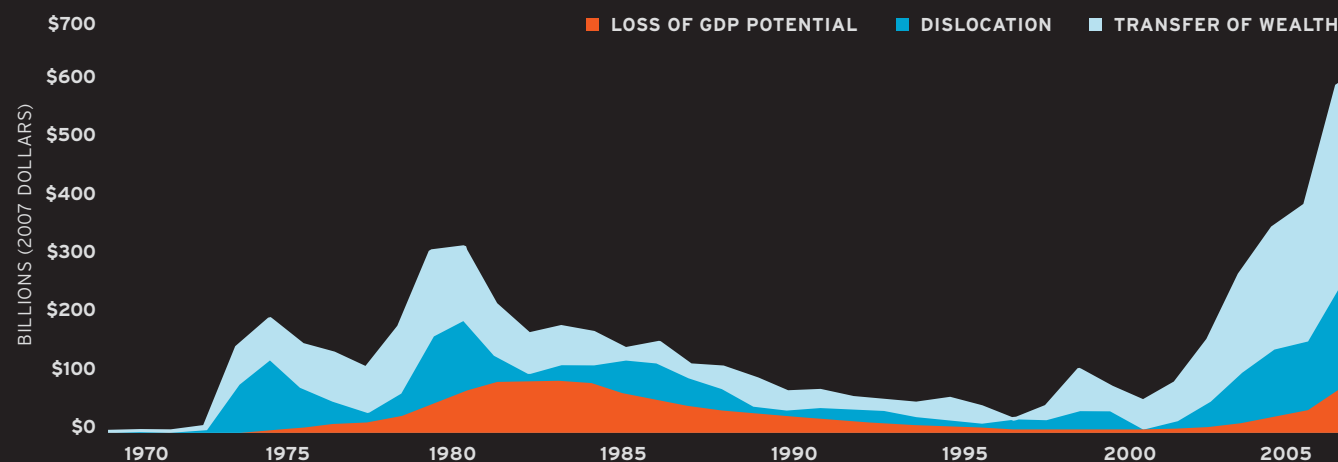
³⁷ "OPEC Revenues Reduce," Forex & Currency Trading, (February 13, 2009), available at forex-trading-currency.org/opec-revenues-reduce, last accessed October 29, 2009.
³⁸ DOE, EIA, "OPEC Revenues Fact Sheet," (October 2008).

FIGURE 1G WORLD NET OIL TRADE, HISTORICAL & FORECAST



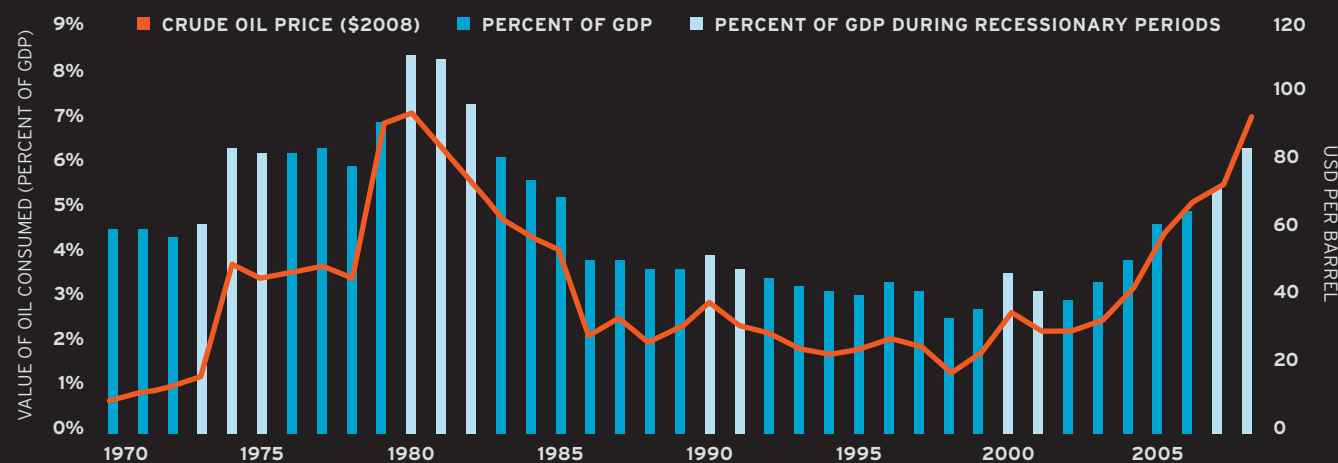
Source: International Energy Agency

FIGURE 1H ECONOMIC COSTS OF U.S. OIL DEPENDENCE



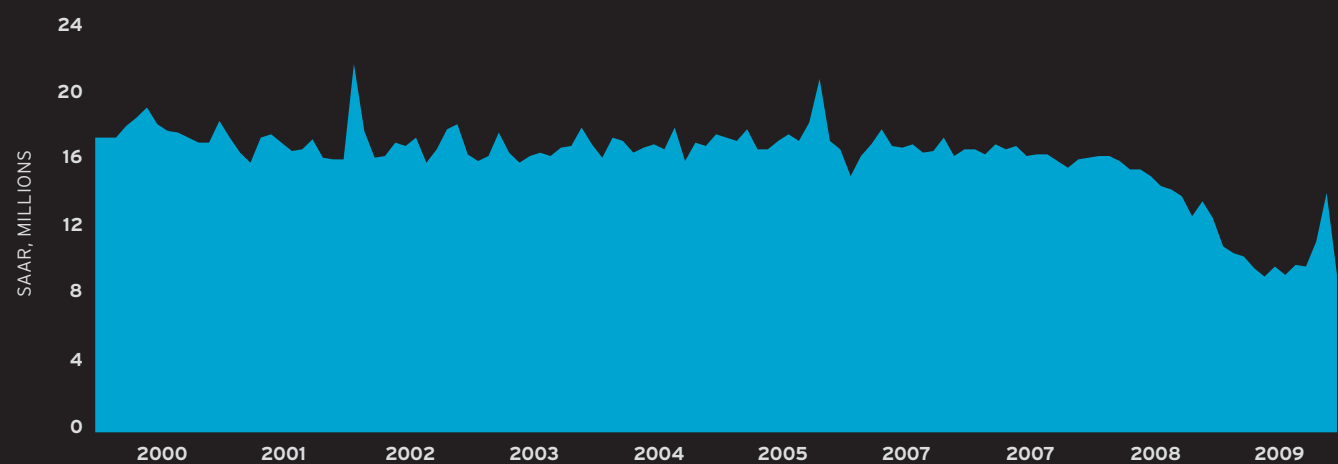
Source: DOE, Office of Energy Efficiency and Renewable Energy

FIGURE 1I OIL PRICES, U.S. OIL EXPENDITURES AND ECONOMIC RECESSIONS



Source: Department of Commerce, Bureau of Economic Analysis

FIGURE 1J U.S. LIGHT VEHICLE SALES



Source: Department of Commerce, Bureau of Economic Analysis; Department of Transportation, Federal Highway Administration

Direct wealth transfer is but one of the many economic costs of American oil dependence. Researchers at the Oak Ridge National Laboratories (ORNL), for example, have studied at least two others. First, significant economic costs stem from the temporary misallocation of resources as the result of sudden price changes. In short, when oil prices fluctuate, it becomes difficult for households and businesses to budget for the long term, and economic activity is significantly curtailed. Second, the existence of an oligopoly inflates oil prices above their free-market cost. As a result, some economic growth is foregone due to higher costs for fuel and other products. ORNL studies estimate the combined damage to the U.S. economy from oil dependence between 1970 and 2008 to be \$5.5 trillion in current dollars.³⁹ For 2008 alone, the cost was nearly \$600 billion (see Figure 1H).

Perhaps most importantly, every recession over the past 35 years has been preceded by—or occurred concurrently with—an oil price spike. In general, recessions are caused by a myriad of factors and are damaging to nearly all sectors of the economy. And yet, oil price spikes tend to exact a particularly heavy toll on fuel-intensive industries like commercial airlines and shipping companies. Additionally, automobile manufacturers tend to suffer disproportionately as consumers dramatically scale back large purchases. But perhaps most important is the effect that oil prices have on consumer spending, which represents about 70 percent of the economy. Stated simply, when consumers have to spend more on gasoline (and heating oil), they have less to spend on everything else.

Volatile fuel prices also tend to hit airlines and shippers hard, because fuel makes up a high percentage of their costs.⁴⁰ The U.S. airline industry lost more than \$35 billion between 2001 and 2005, almost entirely because of expensive jet fuel that they had not been able to predict or plan for.⁴¹ Worldwide estimated

net losses for 2008 were roughly \$10.4 billion,⁴² and the International Air Transport Association (IATA) forecast net 2009 losses for the industry at \$9 billion.⁴³

Similarly, sales of new automobiles can be particularly hard hit. To a large extent, new car sales will decline in a recession, because consumers have less cash to spend and more uncertainty about their personal economic situations. In addition to that concern, which affects all large consumer purchases, consumers might also delay purchasing new cars until they have a better sense of future oil prices and, therefore, how important fuel efficiency will be to their decision. That certainly appears to be the case in the current recession.

In 2007, annual light-duty automobile sales in the United States were approximately 16.1 million units. As oil prices steadily rose throughout 2008, auto sales plummeted. In the closing months of 2008, at the height of the financial crisis, the annualized rate of sales fell to just 9 million units, and two of the three American automotive manufacturers were forced to declare bankruptcy. For the year, auto sales were 13.2 million units in 2008, a decline of approximately 20 percent from 2007. The seasonally adjusted annual rate (SAAR) for 2009 through September is just 10.2 million units, a figure buoyed by high August sales due to the Cash-for-Clunkers program, which brought August sales above a SAAR of 14 million units.^{44,45}

³⁹ David L. Greene, Costs of U.S. Oil Dependence, data available online at www.leere.energy.gov/vehiclesandfuels/facts/2008_fotw522.html.

⁴⁰ According to the Air Transport Association of America, Passenger Airline Cost Index First Quarter 2009, fuel represented 21.3% of operating expenses during the first quarter of 2009. One can appreciate that fuel will represent a higher percentage of overall costs when oil prices are higher than they were at the beginning of the year. See Air Transport Association of America, Passenger Airline Cost Index First Quarter 2009, available online at www.airlines.org/economics/finance/Cost+Index.htm, last accessed on August 20, 2009.

⁴¹ Christopher J. Goodman, Takeoff and Descent of Airline Employment, Monthly Labor Review 3, 8 (October 2008).

⁴² International Air Transport Association, Annual Report 2009. 13 (2009).

⁴³ International Air Transport Association, Financial Forecast Green Shoots Face Severe Headwinds at 1 (2009).

⁴⁴ Green Car Congress, "US LDV Sales Fall 37.1% in January; January SAAR Below 10 Million," (February 3, 2009), available at www.greencarcongress.com/2009/02/us-ldv-sales-fa.html; Autodata Corporation, MotorIntelligence, "SAAR Data," available at www.motorintelligence.com/m_frameset.html.

⁴⁵ Bureau of Economic Analysis, National Data, Motor Vehicles Table 6, available at www.bea.gov/national/index.htm.

1.2.5 Environmental Sustainability

The transportation sector is the single largest end-use emitter of carbon dioxide in the United States, accounting for 34 percent of 2007 total emissions of CO₂.

Finally, concerns about the environmental sustainability of fossil fuels have grown in prominence in recent decades. The Department of Energy reports that transportation is the single largest end-use sectoral emitter of carbon dioxide in the United States, alone accounting for 34 percent of 2007 U.S. emissions.^{46, 47} Total domestic emissions from petroleum—70 percent of which is used in transport—were 2,580 million metric tons (43 percent of total emissions). At current levels, U.S. oil consumption in the transportation sector is simply

inconsistent with even moderate goals for reducing economy-wide emissions of greenhouse gases.

It is important to recognize that curbing emissions is a global issue and that there is not yet an international consensus on a long-term stabilization objective or on the required changes in emissions trajectory to meet such a goal. Nonetheless, international discussions are increasingly centered on a stabilization level that ranges between 450 and 550 parts per million (ppm) CO₂ equivalent (CO₂-eq).⁴⁸ According to the United Nations Intergovernmental Panel on Climate Change, stabilization at 450 ppm CO₂-eq corresponds to a 50 percent chance of restricting the increase in global average temperature to around 2°C, while stabilization at 550 ppm yields a rise of around 3°C.⁴⁹

⁴⁶ Energy Information Administration, CO₂—History from 1949, available online at www.eia.doe.gov/environment.html.

⁴⁷ End-use comparisons can be somewhat misleading, because electric power sector emissions are incorporated throughout the other end-use sectors—residential, industrial and commercial. Still, even if electric power sector emissions are aggregated and isolated, total emissions from that sector were 2,433 million metric tons in 2007, or 40.6 percent of total U.S. emissions of 5,991 million metric tons. By comparison, total transport emissions were 2,014 million metric tons. There is currently no overlap between the electric power and transportation sectors.

⁴⁸ WEO 2008, at 410.

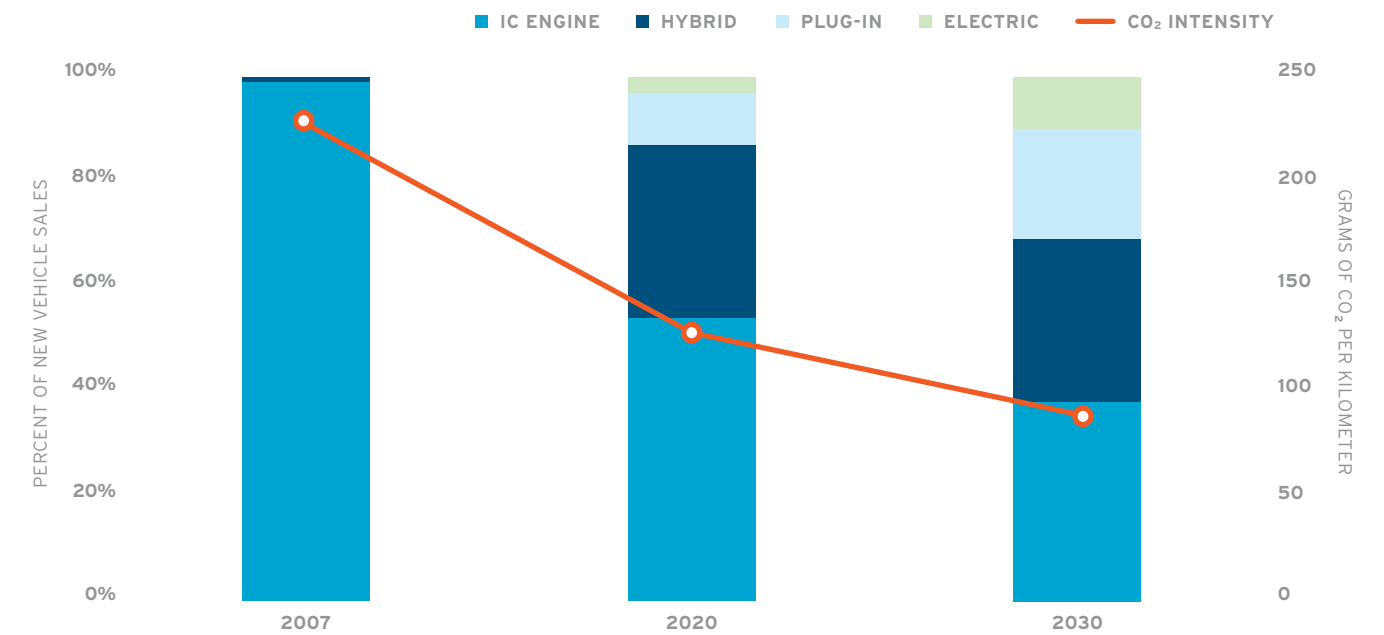
⁴⁹ IEA, World Energy Outlook 2008 at 410.



Downtown Los Angeles lies under a blanket of smog. Given its sprawling nature and number of automobiles, America's second largest city is especially vulnerable to air pollution, as it often experiences temperature inversions which trap the pollution against the San Gabriel Mountains, in the distance.



FIGURE 1K U.S. PASSENGER VEHICLE SALES BY TECHNOLOGY



SOURCE: International Energy Agency

(compared with 1,000 ppm and up to 6°C in the base case).⁵⁰ A 450 ppm CO₂-eq stabilization target would require average annual per-capita CO₂-eq emissions to fall to around 2 metric tons worldwide by 2050, a considerable drop from the current average of 7 metric tons. In the United States, emissions are 26 metric tons per capita.⁵¹

Regardless of the exact nature of a final emissions stabilization target, it is clear that success will be determined in part by the extent to which the increase in GHG emissions in transportation is slowed down or reversed. In a recently released report, the IEA assessed the make-up of U.S. new passenger vehicle sales that would be required to meet a 440 ppm target. The analysis found that by 2030, more than 60 percent of new vehicle sales would need to be based on some form of electrification, ranging from traditional hybrids to pure electric vehicles.⁵²

The transportation sector will most likely provide the greatest opportunities for early emissions abatement in the United States and elsewhere. Low rates of capital-stock turnover, particularly in the power sector, mean that emissions from facilities that have already been built or are under construction are effectively locked in for decades. This limits the scope for the sector to reduce emissions promptly without large-scale retrofitting or very costly early retirement.⁵³ In transportation, however, the capital stock is smaller in size, much more numerous, and lifetimes are closer to 10 years instead of 50 years, offering a meaningful opportunity to achieve rapid emissions displacement with better technology.

⁵⁰ IPCC Fourth Assessment Report, Figure 10.26, p.803.

⁵¹ IEA, World Energy Outlook 2008, at 411.

⁵² IEA, "How the Energy Sector Can Deliver On a Climate Agreement in Copenhagen," Special early excerpt of the World Energy Outlook 2009 for the Bangkok UNFCCC meeting (October 2009).

⁵³ WEO 2008, at 407.

1.3 The Solution



Electrification of transportation is the best solution for dramatically reducing oil dependence. The electric power sector has substantial advantages over the current petroleum-based fuel system, and vehicles fueled by electricity are far more efficient than the conventional vehicles we drive today.

Despite the magnitude of the challenge and decades of political and policy shortfalls, a solution to America's oil dependence is emerging. The United States now has the capacity to permanently enhance its national security and safeguard the economy. To do so, however, the nation must choose to commit to a new path: a fundamental transformation of our transportation sector, moving from cars and trucks that depend on costly oil-based fuels to an integrated system that powers our mobility with domestically-generated electricity.

Electrified transportation has clear advantages over the current petroleum-based system. Electricity represents a diverse, domestic, stable, fundamentally scalable energy supply whose fuel inputs are almost completely free of oil. High penetration rates of grid-enabled vehicles (GEVs)—vehicles propelled by electricity stored onboard in a battery—could radically minimize the importance of oil in the United States,

strengthening our economy, improving national security, and providing much-needed flexibility to our foreign policy. Simultaneously, such a system would clear a path to dramatically reduced economy-wide emissions of greenhouse gases.

This report focuses on the light-duty vehicle fleet (passenger cars and light trucks with a gross-vehicle weight of less than 8,500 pounds) for electrification. A number of automakers are currently investing in light-duty GEV platforms that are competitive with the petroleum-dependent passenger cars and trucks we use today. GEVs offer superior performance in terms of efficiency, fuel costs, and carbon emissions. They also provide drivers with greater torque and acceleration than conventionally-powered vehicles.

It is important to note that this Roadmap's focus on light-duty vehicles is in no way meant to preclude efficiency gains in other highway transportation modes. Medium- and heavy-duty freight trucks in particular are significant consumers of petroleum for which hybridization and ultimately electrification may be viable technologies. However, the size and scale of the light-duty fleet and its prominent role in U.S. oil consumption clearly command a high level of prioritization.



Recharging a 1999 Nissan Altra EV Electric Station Wagon



1.3.1 The Power of Electricity

The electric power sector is a scalable source of energy based on an existing infrastructure. The fuels used to generate electricity are diverse and domestic, and electricity prices exhibit long-term stability.

The primary advantages of electrification derive from replacing petroleum fuels in our light-duty vehicles with electricity. Total U.S. oil demand over the five years from 2004 through 2008 averaged 20.4 million barrels per day.⁵⁴ Over the same period, oil demand within the aggregate transportation sector averaged 13.9 mbd.⁵⁵ However, light-duty vehicles—cars, SUVs and motorcycles—accounted for approximately 8.6 mbd of total transportation demand. That is, passenger vehicles currently account for roughly 40 percent of total U.S. petroleum demand. Electrification would allow the transportation sector to access a number of strategic advantages of the electric power sector.

ELECTRICITY IS DIVERSE AND DOMESTIC

Perhaps most importantly from an energy security standpoint, electricity is generated from a diverse set of largely domestic fuels, including coal, uranium, natural gas, flowing water, wind, geothermal heat, the

sun, landfill gas, and others.⁵⁶ Among those fuels, the role of petroleum is negligible. In fact, just 1 percent of power generated in the United States in 2008 was derived from petroleum.

An electricity-powered transportation system, therefore, is one in which an interruption of the supply of one fuel can be made up for by others, even in the short term, at least to the extent that there is spare capacity in generators fueled by other fuels, which is generally the case.⁵⁷ This ability to use different fuels as a source of power would increase the flexibility of an electrified light-duty vehicle fleet. As our national goals and resources change over time, we can shift transportation fuels without overhauling our transportation infrastructure. In short, an electrified transport system would give us back the reins, offering much greater control over the fuels we use to support the transportation sector of our economy.

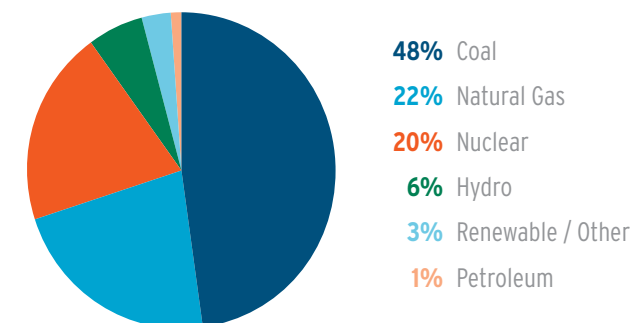
54 BP plc, Statistical Review of World Energy 2009, at 12 (2009). Note: Includes ethanol.

55 AER 2008, at 156 (Table 5.13c). Note: Includes ethanol.

56 Department of Energy, Energy Information Administration, Electric Power Annual 2007 at 2 (2009) (hereinafter EPA 2007).

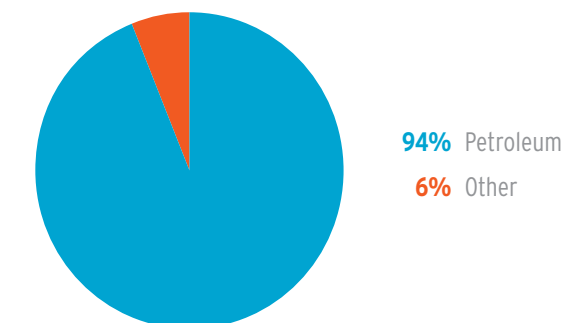
57 Id. at 102 (Table A.6).

FIGURE 1L U.S. POWER GENERATION BY FUEL



Source: DOE, EIA

FIGURE 1M U.S. TRANSPORT ENERGY BY FUEL



Source: DOE, EIA

Moreover, while oil supplies are subject to a wide range of geopolitical risks, the fuels that we use to generate electricity are generally sourced domestically. All renewable energy is generated using domestic resources. We are a net exporter of coal,⁵⁸ which fuels about half of our electricity.⁵⁹ Although we currently import approximately 16 percent of the natural gas we consume,⁶⁰ more than 90 percent of those imports were from North American sources (Canada and Mexico) in 2008.⁶¹ We do import a substantial portion of the uranium we use for civilian nuclear power reactors. Forty-two percent of those imports, however, are from Canada and Australia.⁶²

ELECTRICITY PRICES ARE STABLE

Electricity prices are significantly less volatile than oil or gasoline prices. Over the past 25 years, electricity prices have risen steadily but slowly. Since 1983, the average retail price of electricity delivered in the United States has risen by an average of less than 2 percent per year in nominal terms and has actually fallen in real terms.⁶³ Moreover, prices have risen by more than 5 percent per year only three times in that

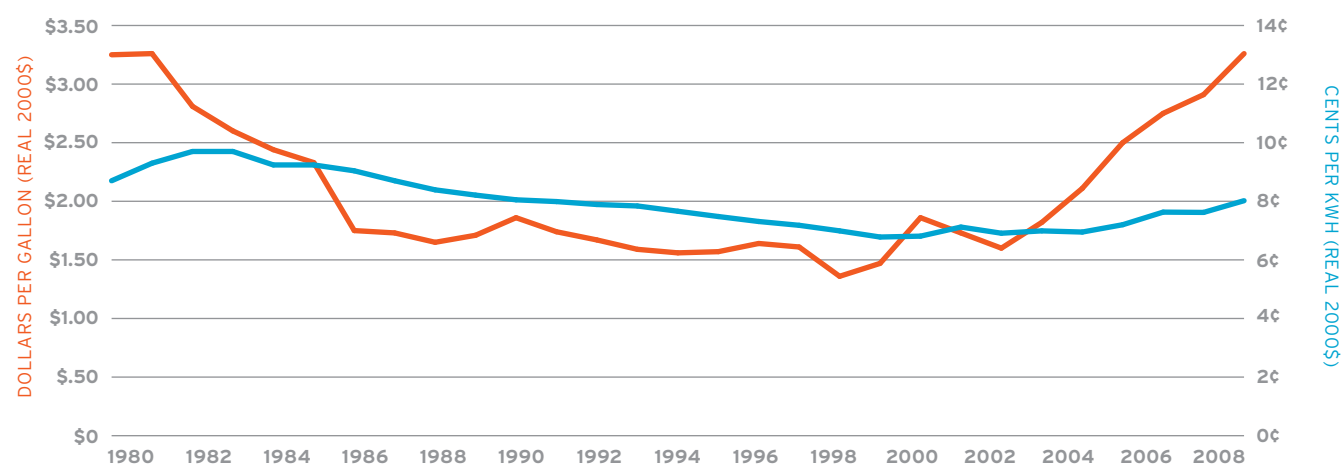
time period.⁶⁴ This price stability, which is in sharp contrast to the price of oil or gasoline, exists for at least two reasons.

First, the retail price of electricity reflects a wide range of costs, only a small portion of which arise from the underlying cost of the fuel. The remaining costs are largely fixed.⁶⁵ In most instances, the cost of fuel represents a smaller percentage of the overall cost of delivered electricity than the cost of crude oil represents as a percentage of the cost of retail gasoline.⁶⁶ For instance, although fossil fuel prices rose 21 percent between 2004 and 2006 (as measured on a cents-per-Btu basis),⁶⁷ and the price of uranium delivered in 2006 rose 48 percent over the cost of uranium delivered in 2004,⁶⁸ the national average retail price of all electricity sales increased only 17 percent (from 7.6 cents per kWh to 8.9 cents per kWh);⁶⁹ the average price of residential electricity rose only 16 percent (from 8.95 to 10.4 cents per kWh).⁷⁰ This cost structure promotes price stability with respect to the final retail price of electricity.

58 Fred Freme, Department of Energy, Energy Information Administration, "U.S. Coal Supply and Demand 2008 Review," at 11-13 (2009) available online at www.eia.doe.gov/cneaf/coal/page/special/article_dc.pdf, last accessed on October 22, 2009.
 59 EPA 2007 at 2.
 60 AEO 2009 at 78.
 61 AER 2008 at 191 (Table 6.3).
 62 Department of Energy, Energy Information Administration, 2008 Uranium Marketing Annual Report at 1 (2009) (hereinafter UMAR 2008).
 63 AER 2008 at 261 (Table 8.10).

64 Id.
 65 Department of Energy, Energy Information Administration, "Energy in Brief-What Everyone Should Know: How is my Electricity Generated, Delivered, and Priced?," available at tonto.eia.doe.gov/energy_in_brief/electricity.cfm, last accessed on October 22, 2009.
 66 See Department of Energy, Energy Information Administration, "Gasoline Explained: Factors Gasoline Prices," available at www.eia.doe.gov/bookshelf/brochures/gasolinepricesprimer/, last accessed on October 22, 2009; EPA 2007, at 69 (Table 8.2).
 67 EPA 2007 at 48 (Table 4.5).
 68 UMAR 2008, at 3 (Table S.L.b).
 69 AER 2008 at 261 (Table 8.10).
 70 Id.

FIGURE 1N RETAIL PRICES: GAS VS. ELECTRICITY ■ GASOLINE ■ ELECTRICITY (AVG, ALL SECTORS)



Source: DOE, EIA



Second, although real-time electricity prices are volatile (sometimes highly volatile on an hour-to-hour or day-to-day basis)⁷¹ they are nevertheless relatively stable over the medium and long term. Therefore, in setting retail rates, utilities or power marketers use formulas that will allow them to recover their costs, including the occasionally high real-time prices for electricity, but which effectively isolate the retail consumer from the hour-to-hour and day-to-day volatility of the real-time power markets.⁷² By isolating the consumer from the price volatility of the underlying fuel costs, electric utilities would be providing to drivers of GEVs the very stability that oil companies cannot provide to consumers of gasoline.

THE POWER SECTOR HAS SUBSTANTIAL SPARE CAPACITY

Because large-scale storage of electricity has historically been impractical, the U.S. electric power sector is effectively designed as an 'on-demand system.' In practical terms, this has meant that the system is constructed to be able to meet peak demand from existing generation sources at any time. However, throughout most of a 24-hour day—particularly at night—consumers require significantly less electricity than the system is capable of delivering. Therefore, the U.S. electric power sector has substantial spare capacity that could be used to power electric vehicles without constructing additional power generation facilities, assuming charging patterns were appropriately managed.

THE NETWORK OF INFRASTRUCTURE ALREADY EXISTS

Unlike many proposed alternatives to petroleum-based fuels, the nation already has a ubiquitous network of electricity infrastructure. No doubt, electrification will require additional functionality and increased investment in grid reliability, but the power sector's infrastructural backbone—generation, transmission, and distribution—is already in place.

71 Sustainable Energy Advantage, LLC, "Using Wind Power to Hedge Volatile Electricity Prices for Commercial and Industrial Customers in New York," at 2-3 (2003) available online at www.powernaturally.org/About/documents/WindHedgeExSumm.pdf, last accessed on August 19, 2009.
 72 Department of Energy, Energy Information Administration, "Energy in Brief-What Everyone Should Know: How is my Electricity Generated, Delivered, and Priced?," available online at tonto.eia.doe.gov/energy_in_brief/electricity.cfm, last accessed on October 22, 2009.

THE IMMENSE POTENTIAL OF ELECTRIC PROPULSION

In order to harness the strategic advantages of the electric power sector in the light-duty vehicle fleet, vehicles that can be propelled by electricity must be available to consumers. In fact, the technology for such vehicles has advanced rapidly in recent years. Though important challenges remain, the global automotive industry has invested heavily in highly-efficient electric drive vehicles that use reduced quantities of petroleum in order to meet consumer demand in an era of high fuel prices, and to comply with increasingly stringent regulations that restrict tailpipe CO₂ emissions.

A variety of technologies employing electric drive are on the cusp of commercial availability, and an even larger number are currently in the final stages of development. In general, grid-enabled vehicles can be either pure electric vehicles (EVs) or plug-in hybrid electric (PHEVs). Both EVs and PHEVs store energy from the grid in onboard batteries. Energy from the battery powers a highly-efficient electric motor that propels the vehicle. EVs substitute an electric drivetrain for all conventional drivetrain components. PHEVs retain the use of a down-sized internal combustion engine that supplements battery power. (These technologies are reviewed in greater detail in Part Two of this Roadmap.) At a basic level, both EVs and PHEVs provide consumers with clear advantages compared to gasoline powered conventional vehicles of today.

ELECTRIC MILES ARE CHEAPER THAN GASOLINE MILES

Operating a vehicle on electricity in the United States is considerably less expensive than operating a vehicle on gasoline. In large part, this is due to the high efficiency of electric motors, which can turn more than 90 percent of the energy content of electricity into mechanical energy. In contrast, today’s best internal combustion engines have efficiency ratings of just 25 to 27 percent. With gasoline at \$3.00 per gallon, the operating cost of a highly-efficient IC engine vehicle (30 miles per gallon) is 10 cents per mile. For current pure electric vehicles, assuming an average electricity price of 10 cents per kilowatt hour, operating costs are only 2.5 cents per mile.

Recent research confirms the potential savings of electric propulsion. The Electric Power Research Institute has determined that a compact size plug-in electric hybrid vehicle will use only 160 gallons of gasoline a year, compared to 300 in a traditional gasoline electric hybrid and 400 in a conventional internal combustion engine compact car. With gasoline at \$3 a gallon, a plug-in hybrid would save its owner \$10,000 over the course of the vehicle’s lifetime compared to a conventional vehicle.⁷³

ELECTRIC MILES ARE CLEANER THAN GASOLINE MILES

Vehicle miles fueled by electricity emit less CO₂ than those fueled by gasoline. Several well-to-wheels analyses conclude that even vehicles powered by the full and proportionate mix of fuel sources in the United States today would result in reduced carbon emissions. As renewable power increases its share of the electricity portfolio, and to the extent that new nuclear power comes on line, the emissions profile of the U.S. power sector and the GEVs powered by it will continue to improve over time. Moreover, to the extent that GEVs are charged overnight using power from baseload nuclear or off-peak renewable power, their emissions footprint can be nearly eliminated.

Well-to-wheels analyses examine the energy use and carbon emissions attributable to a vehicle from the time an energy source is extracted until it is

consumed.⁷⁴ In 2007, the Natural Resources Defense Council and the Electric Power Research Institute published a well-to-wheels analysis of several different automotive technologies fueled by a range of sources commonly used to generate power.⁷⁵ Their analysis concluded that using a PHEV would reduce carbon emissions as compared to a petroleum-fueled vehicle, even if all of the exogenous electricity used to charge the PHEV was generated at an old (relatively dirty) coal power plant.

Whereas a conventional gasoline vehicle would be responsible for emissions, on average, of 450 grams of CO₂ per mile, a PHEV that was charged with power generated at an old coal plant would be responsible for emissions of about 325 grams of CO₂ per mile, a reduction of about 25 percent.⁷⁶ Emissions attributable to the vehicle could be reduced to as low as 150 grams of CO₂ per mile if the exogenous power was generated at a plant without carbon emissions and ranged between 200 and 300 grams of CO₂ per mile if the power used was generated using other fossil fuel generation technologies.⁷⁷ In other words, no matter where the power consumed by a PHEV is generated, the overall level of emissions attributable to its operation are lower than those of a conventional gasoline vehicle.⁷⁸

Not only are GEVs cleaner than traditional vehicles today, they will continue to get cleaner over time without any additional changes to the vehicles themselves. If climate change legislation passes and imposes new emissions standards on power plants, their improved emissions profile will also represent an improvement of GEVs’ emissions profile. Finally, it is important to note that, in some parts of the country, baseload nuclear power and/or renewable power provide a substantial portion of off-peak power. To the extent that GEVs charge overnight in such regions, carbon emissions attributable to their operation would be reduced to perhaps as low as zero.

74 Matthew A. Kromer and John B. Heywood, *Electric Powertrains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet*, Massachusetts Institute of Technology at 24 (2007) available online at web.mit.edu/sloan-auto-lab/research/beforeh2/files/kromer_electric_powertrains.pdf, last accessed on August 19, 2009.

75 Electric Power Research Institute, Natural Resources Defense Council & Charles Clark Group, *Environmental Assessment of Plug-In Hybrid Electric Vehicles: Volume 1: Nationwide Greenhouse Gas Emissions (2007)* available online at mydocs.epri.com/docs/public/000000000001015325.pdf, last accessed on August 30, 2009.

76 Id. at 7.

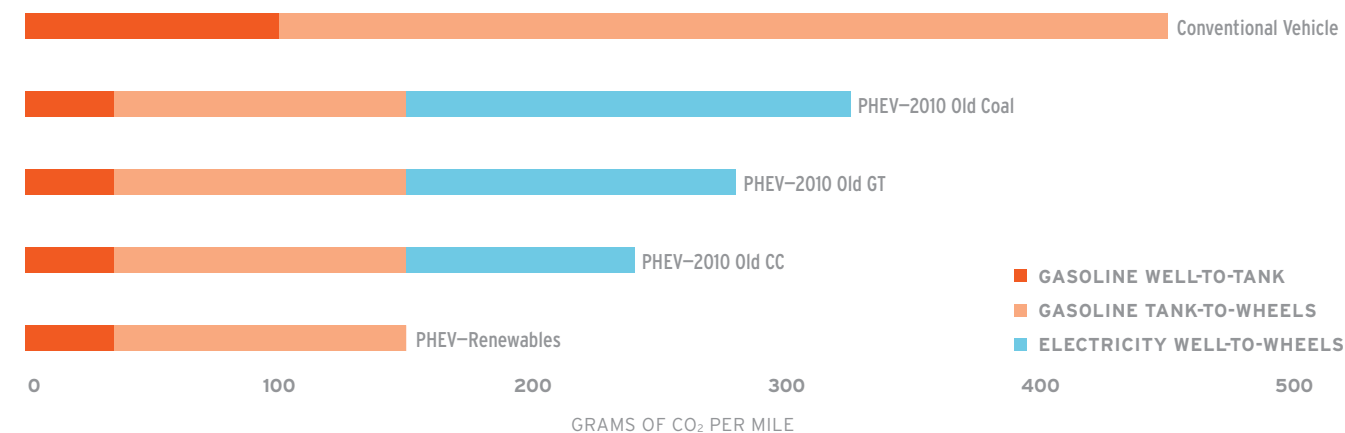
77 Id.

78 Id.

73 Tom Reddoch, *Electric Transportation and Energy Efficiency*, (Electric Power Research Institute Briefing to the Energy Task Force, State of Tennessee, Franklin, Tennessee, September 19, 2008) at 8, available online at bree.tnanytime.org/energy/sites/default/files/EPRI%20Final%2009-19-08.pdf, last accessed on August 19, 2009.



FIGURE 10 VEHICLE EMISSIONS BY TECHNOLOGY AND FUEL



Source: Electric Power Research Institute; Natural Resources Defense Council

GRID-ENABLED VEHICLES AND THE 21ST CENTURY TRANSPORTATION ARCHITECTURE

Over the course of the last hundred years, the United States has developed two enormous but entirely distinct energy provision systems: stationary electricity and mobile internal combustion engines. Our power plants and our vehicles are currently completely independent and isolated from each other.

By converging the electric power sector with the transportation sector, the United States will import the advantages of electricity into our vehicles. The diversity and stability that characterize our electric system will strengthen our transportation system as well, enhancing national and economic security and vastly improving the consumer transportation experience. We will pay less for our fuel; enjoy increased power, torque, and acceleration; benefit from decreased noise and emissions; and increase our economic flexibility at both a personal and national level.

To be sure, deeply ingrained norms associated with conventional vehicles will be altered by grid-enabled vehicles. Early vehicles may have limited ranges, though the minimum range for all-electric drive in most vehicles is already well in excess of the daily needs of a majority of Americans. Moreover, the higher upfront costs of today’s GEVs necessarily entail a long-term value proposition. Yet, by driving innovation through scale, vehicle costs will fall, range will certainly expand, and flexibility will only increase.

Ultimately, the benefits of a widely deployed electric vehicle network will also feed back to the grid.

Approximately 160 million vehicles, or around 65 percent of the present U.S. light-duty vehicle stock, could be powered solely by existing off-peak generating capacity.⁷⁹ Grid-enabled vehicles will be plugged into the electric grid for much of the time that they are not on the road. Utilities can optimize the use of these batteries, meeting the needs of all consumers, including motorists, at the lowest possible cost. In short, motorists and the utilities can be thought of as having complementary interests.

Renewable energy will play an increasing role in U.S. power generation. The principal difficulty with wind and solar power is their intermittent nature. GEVs will not only improve national and economic security, they will also act as distributed storage devices for electricity, enabling utilities to even out fluctuating energy production. Vehicle batteries can become storage devices capable of supporting the grid during periods of peak demand. Recent advances in smart metering, online billing, and vehicle-to-grid (V2G) technology enable a revolution in communication between homes, vehicles, utilities, and renewable energy sources. Our electric and vehicle infrastructures will converge, creating synergies and vastly increasing the overall efficiency of our entire energy system.

79 Kintner-Meyer, Michael et al, “Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 1: Technical Analysis,” Pacific Northwest National Laboratory, January 2007; Scott, Michael J. et al, “Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids Part 2: Economic Assessment,” Pacific Northwest National Laboratory, November 2007.

FIGURE 1P Electrification Architecture

(48%) COAL GENERATION
Coal is the dominant fuel source in U.S. power generation, and domestic resources are abundant. Concern regarding emissions has led to investments in technology to capture and sequester CO₂ emissions.

(22%) NATURAL GAS GENERATION
Advances in technology have unlocked substantial natural gas resources in the United States. Burning natural gas emits less CO₂ than coal or oil.

(20%) NUCLEAR GENERATION
Nuclear power is an emissions-free source of baseload power. Some uranium is imported, but from stable suppliers like Canada and Australia.

(9%) RENEWABLE GENERATION
Renewable sources of electricity like wind, solar, geothermal, and hydropower are growing sources of emissions-free domestic energy.

Power Storage
Because wind and solar power are intermittent, they require augmentation. Today, natural gas turbines often perform this function, but stationary lithium-ion batteries may ultimately prove more cost-effective.

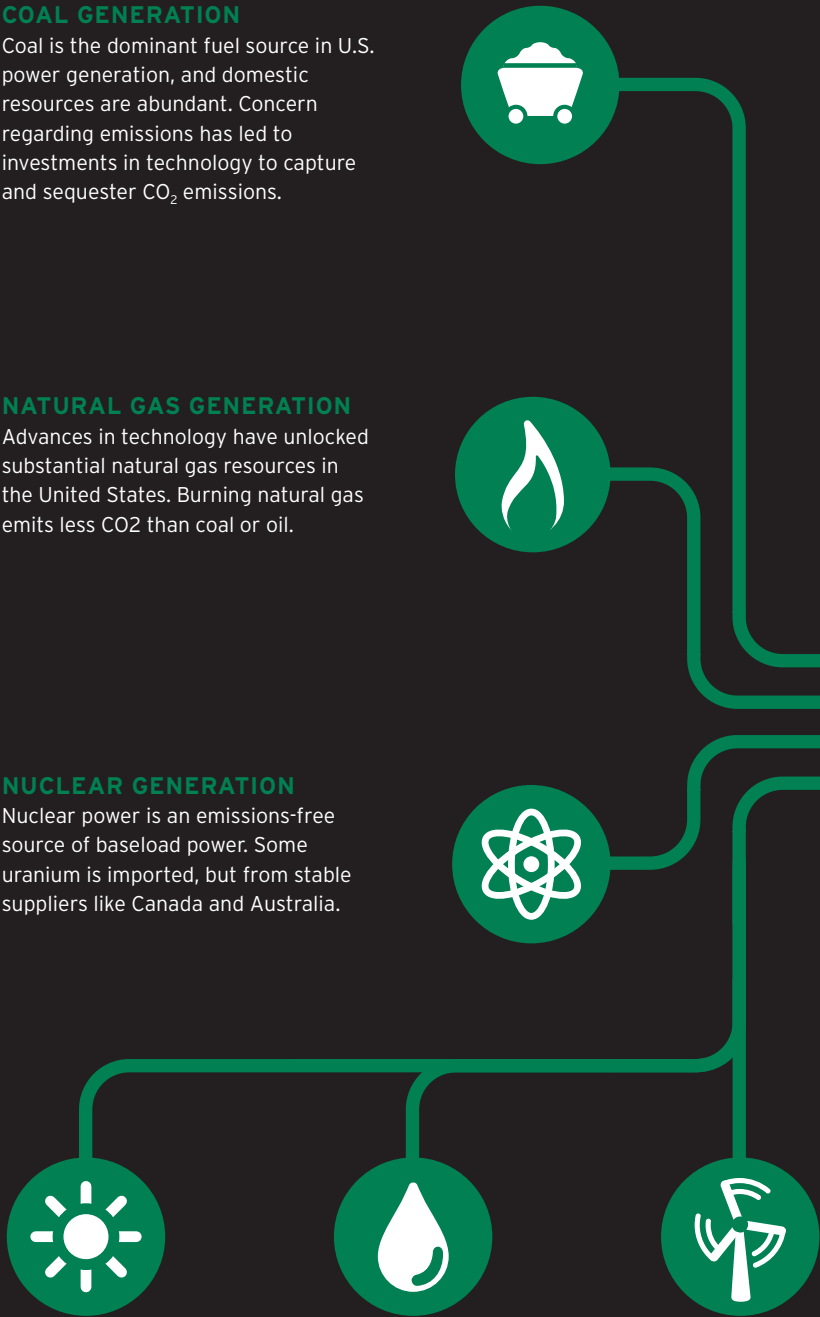
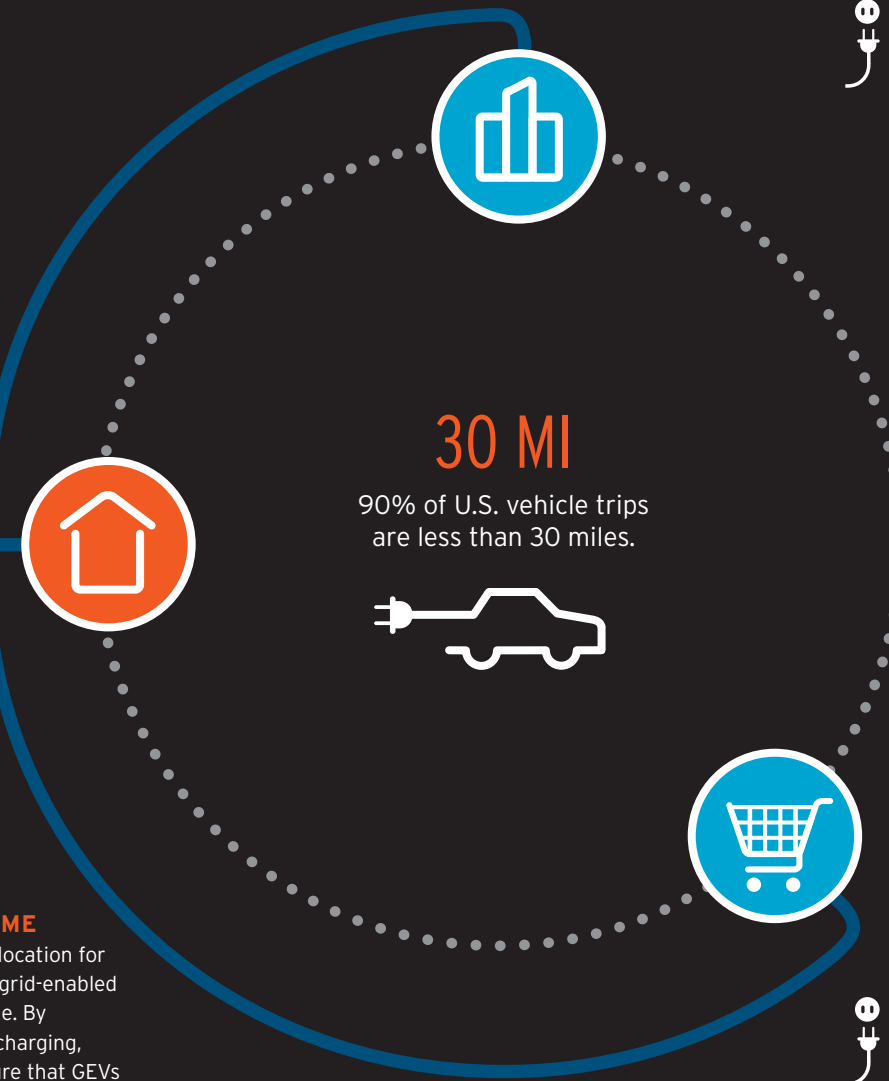
TRANSMISSION AND DISTRIBUTION
Electricity from America's diverse set of generation sources is delivered to consumers via a widespread network that already exists today.

The U.S. transportation system and the electric power sector are completely separate today. The emergence of grid-enabled vehicles offers the possibility to synergize these two systems for the first time. In doing so, the transportation system would access the fuel diversity and price stability of the electric power sector, thus substantially improving U.S. energy security.

WORKPLACE
During the day, while GEVs sit idle at the driver's workplace, a network of lithium-ion batteries could function as a valuable source of peak power supply for the electric grid.

RESIDENTIAL HOME
The primary charging location for most non-commercial grid-enabled vehicles will be at home. By encouraging off-peak charging, policymakers can ensure that GEVs take advantage of substantial spare capacity in the power sector.

RETAIL LOCATIONS
Access to electric vehicle supply equipment at retail locations could allow drivers to charge while shopping. It would also increase early consumer confidence in GEVs and provide retailers with a marketing opportunity.



1.4 The Target



The United States should set a specific and measurable goal for the widespread deployment of grid-enabled vehicles. Such a target will provide Americans with a clear definition of success and help lawmakers to focus policy efforts over the coming decades. The target should be ambitious but achievable with the right mix of consumer incentives and regulatory stability.

Deploying electric vehicles at scale will require nothing less than a fundamental transformation of mobility for the vast majority of Americans and for the nation as a whole. It will require a sustained political commitment in an era of complex fiscal pressures and fluctuating oil prices. While electrification benefits from the pre-existing network of electricity generation and distribution, some new national infrastructure will have to be constructed to meet consumer charging needs.

Before committing resources to a national undertaking of this scale, it is important to have a sense of how success will be defined and to identify the tools

at the nation's disposal that can drive advancement. A well-defined goal is needed, as are benchmarks by which the nation can measure progress over what promises to be a decades-long effort. Moreover, political leaders need to be clear

about the strengths and weaknesses of the existing policy framework and be prepared to concentrate their efforts on minimizing barriers to electrification. Last year, President Barack Obama established a goal of getting 1 million grid-enabled vehicles onto the road by 2015. Together, Congress and the president have directed substantial funds from the Energy Independence and Security Act (2007) and the American Reinvestment and Recovery Act (2009) in pursuit of that goal. That investment alone, however, is insufficient to meet the president's target. To be sure, existing electrification programs and funding should be leveraged to their maximum extent. But deploying GEVs at scale will require long-term regulatory stability and consistent prioritization in the near term. With this in mind, this Roadmap sets a more ambitious target for electrification that will not only meet the president's goal, but ultimately greatly exceed it.

Over the coming decades, public and private research and development (R&D) efforts may yield significant advancements in a range of energy technologies. Today's high-risk research may ultimately produce future transportation fuels and electricity generation platforms far superior to anything that policymakers and industry are considering today. Such advancements are not only plausible, they will likely be necessary. The energy sector faces a myriad of challenges in the coming decades. Global primary energy demand is expected to increase by nearly 50 percent between today and 2030. The International Energy Agency recently reported that the world will need to invest \$26 trillion (2007 dollars) in energy supply infrastructure in order to meet demand in 2030.

For these reasons, it is utterly imperative that public and private entities maintain aggressive efforts to explore a range of energy technology pathways. At the same time, the high costs of oil dependence demand that policymakers in the United States take action today to safeguard economic growth and enhance our national security. Electrification of transportation must be pursued to address these risks, but also offers a balanced technological strategy that will provide maximum flexibility for the power and transportation sectors to evolve in the coming decades. As R&D continues to yield improvements in energy technology, the country must constantly assess breakthroughs and their impact on strategy and policy.

By 2040, 75% of the light-duty vehicle miles traveled in the U.S. should be electric miles.

More success will be defined and to identify the tools

at the nation's disposal that can drive advancement. A well-defined goal is needed, as are benchmarks by which the nation can measure progress over what promises to be a decades-long effort. Moreover, political leaders need to be clear about the strengths and weaknesses of the existing policy framework and be prepared to concentrate their efforts on minimizing barriers to electrification. Last year, President Barack Obama established a goal of getting 1 million grid-enabled vehicles onto the road by 2015. Together, Congress and the president have directed substantial funds from the Energy Independence and Security Act (2007) and the American Reinvestment and Recovery Act (2009) in pursuit of that goal. That investment alone, however, is insufficient to meet the president's target. To be sure, existing electrification programs and funding should



1.4.1 A National Goal for Electrification

The United States has set ambitious goals in order to advance the national interest in the past. Today, to safeguard national security, the country must commit to a transformed transport sector.

The national goal should be the complete transformation of the light-duty vehicle fleet into one in which grid-enabled mobility is the new standard. By 2040, 75 percent of the light-duty vehicle miles traveled (VMT) in the United States should be electric miles. As a result, oil consumption in the light-duty fleet would be reduced to just 2.0 mbd, compared to today's level of 8.6 mbd, and it is conceivable that U.S. oil imports could effectively be reduced to zero. Carbon emissions in the transportation sector would be reduced to 601 million tons with today's generation mix, and 525 million tons with a generation mix that derived 40 percent of its power from nuclear and renewables.

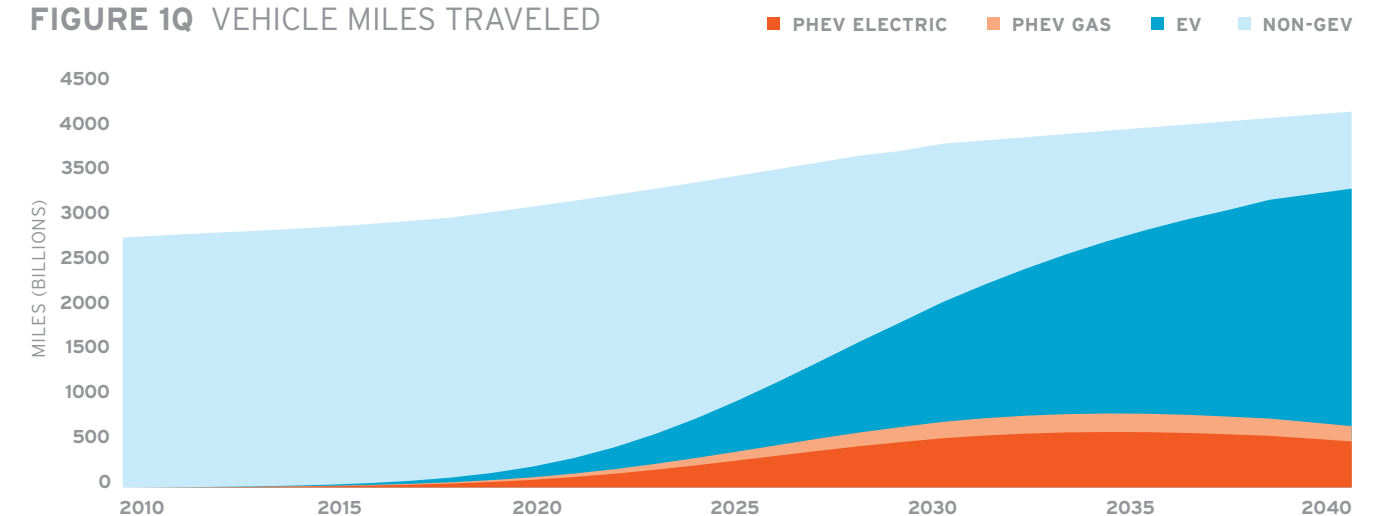
Meeting this goal will be a formidable challenge. It will require aggressive investment in public infrastructure and immediate acceleration of technological development—particularly for batteries—in order to drive down costs. Most importantly, it will require rapid acceptance of grid-enabled vehicles by consumers, measured by high levels of penetration in new vehicle sales. Only by reaching and sustaining these levels can the total vehicle fleet be 'turned over' within a reasonable timeframe. Annual light-duty

vehicle (LDV) sales in the United States averaged more than 16 million units between 2000 and 2008. Each year, new sales represent just 7 percent of total on-road vehicles.

Today, there are roughly 250 million LDVs on the road in the United States. According to Department of Energy forecasts, by 2030 that figure will rise by nearly 20 percent to 294 million. In 2008, the median lifespan of cars in use was 9.4 years. For light trucks, the figure was 7.5 years.⁸⁰ More tellingly, a typical car will travel 150,000 miles in its lifetime, and even after 15 years, 33 percent of cars are still on the road.⁸¹ These figures only begin to convey the monolithic proportions of the U.S. LDV fleet. They put into sharp relief the challenge: deploying grid-enabled vehicles in quantities sufficient to displace a large fraction of U.S. oil consumption will take decades. How many decades is a matter of how quickly high rates of new vehicle sales can become dominated by GEVs.

80 Transportation Energy Data Book 2008, Table 3.9, "Median Age of Cars and Trucks in Use, 1970-2008," at 3-12.
81 Transportation Energy Data Book 2008, Table 3.10 "Car and Light Truck Survivability Rates and Lifetime Miles," at 3-14.

FIGURE 1Q VEHICLE MILES TRAVELED



Source: PRTM Analysis

1.4.2 Critical Milestones

Specific milestones will assist lawmakers in measuring progress toward widespread electrification. Milestones should take into consideration the number of grid-enabled vehicles sold and on the road in order to assess the competitiveness of the technology.

MILESTONE ONE

In order to reach the goal of 75 percent electric miles by 2040, the U.S. light-duty vehicle market will need to have reached a tipping point by 2020. This is defined as the point at which grid-enabled vehicles represent 25 percent of new LDV purchases. The specific technology—plug-in hybrid electric or pure electric—is not as important as the share that such vehicles represent of the new vehicle portfolio. Different GEV technologies will meet different drivers' needs, but the concept of electrification cannot move beyond a niche application until at least one-quarter of new vehicle consumers are willing to adopt the technology.

Figure 1R notes the required EV and PHEV sales penetration level for 2020 in order to successfully reach Milestone One. Note that even at this level of new vehicle sales, GEVs would represent just 5.3 percent of the entire vehicle fleet, and would displace only about 490,000 barrels per day of petroleum consumption.

However, the importance of reaching Milestone One cannot be overstated. By quickly ramping up to high levels of new vehicle penetration, GEVs can establish a foothold in the light-duty vehicle marketplace, which will allow them to achieve a progressively greater share of the LDV fleet over the period 2020 to 2040.

MILESTONE TWO

Beyond 2020, grid-enabled vehicles will need to continue to grow as a share of new light-duty vehicle sales until they surpass 90 percent in 2030. At that point, the rate of penetration will flatten out and run asymptotic to the maximum sales penetration rate, which is estimated to be approximately 95 percent. Over the following 10 years—2030 to 2040—maintaining this sales penetration rate allows total fleet penetration to reach 70 percent by 2040. In this scenario, by 2040, 75 percent of all LDV miles traveled in the United States would be electric.

Figure 1R displays the LDV sales penetration curves for EVs and PHEVs between 2010 and 2040. Milestone Two is achieved in 2030 and the curves flatten out to the goal year, 2040. Figure 1S displays the total LDV fleet penetration that results from the sales penetration rate depicted by Figure 1R. The curve lags sales penetration, but by a decreasing margin over time. At this level, GEVs offset 2040 oil consumption in the light-duty vehicle fleet by 6.2 mbd, or 75 percent compared to the base case.

FIGURE 1R REQUIRED SALES PENETRATION

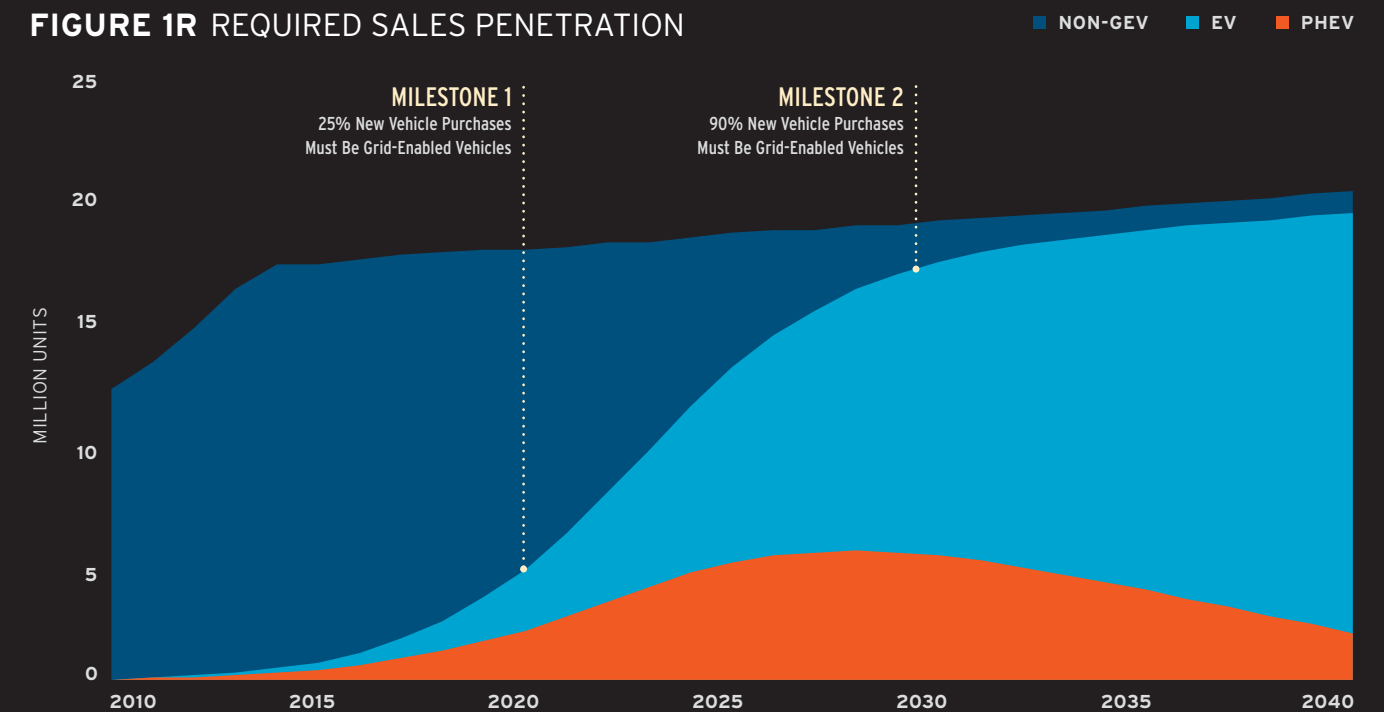
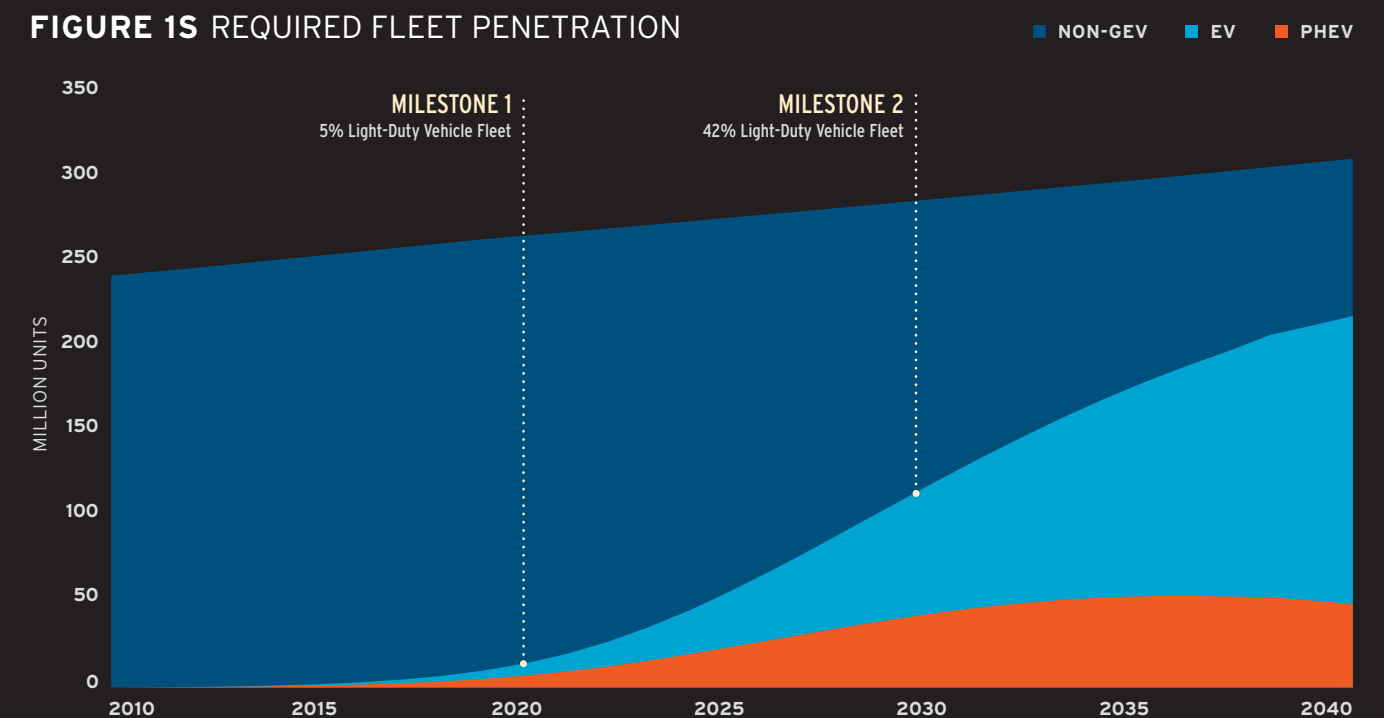


FIGURE 1S REQUIRED FLEET PENETRATION



Source: PRTM Analysis

1.4.3 Assessing the Goal's Feasibility

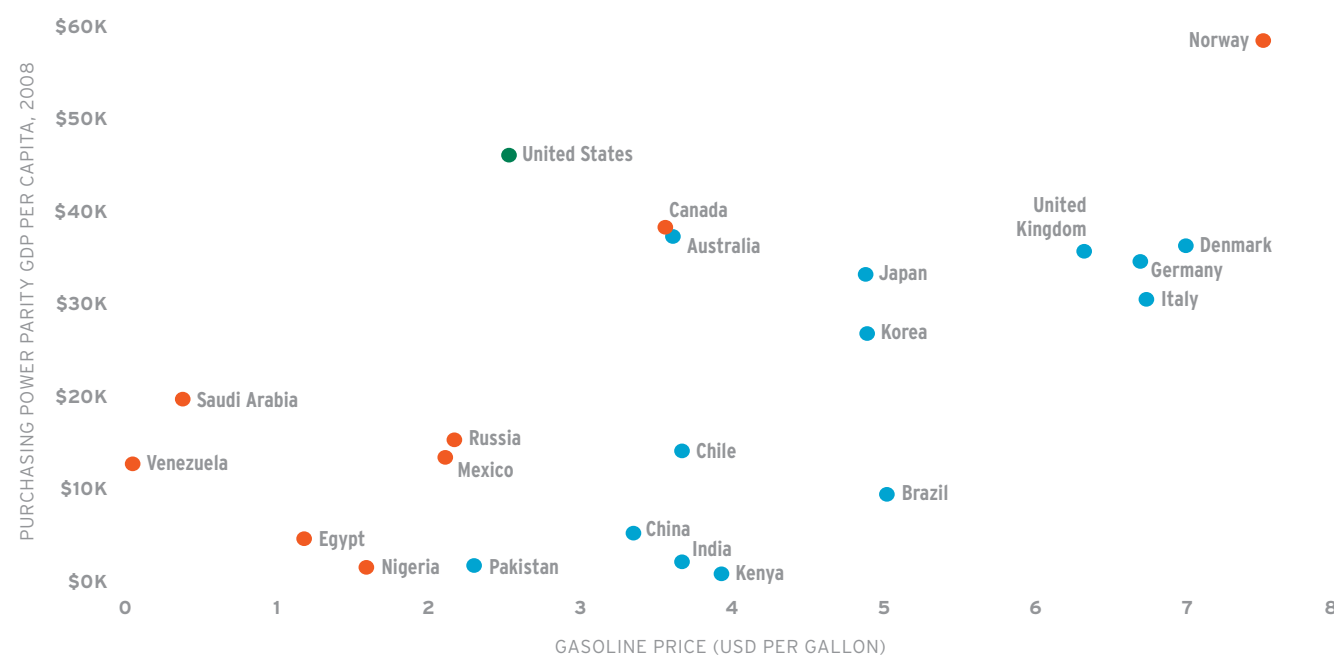
Achieving the rate of GEV deployment targeted by the national goal would substantially improve American economic and national security. However, it is important to be clear-eyed about the steps required to accomplish such a goal.

This Roadmap sets an ambitious target for grid-enabled vehicle adoption. Today, there is only one commercially available and highway capable grid-enabled vehicle for consumers in the United States. The internal combustion engine has enjoyed 100 years of market dominance, during which time it has helped propel the United States to the forefront of the global economy and met nearly every need imaginable for U.S. drivers. In the short to medium term, the targets for GEV sales penetration presented here represent the upper bound of industry forecasts. Over the long term, forecasting GEV adoption is highly speculative, but it is nevertheless likely that the sales and fleet penetration targets we have set for 2040 will be well in excess of the upper bound of industry forecasts.

It is, therefore, critically important to distinguish between a goal and a forecast. With appropriate government incentives and a firm long-term commitment, electrified transportation will offer a compelling alternative to the petroleum-based system of today. But what has been set forward here is not a forecast of adoption based on the status quo policy environment. Electrified transport might achieve some measure of competitiveness over the coming decades based on oil prices, environmentalism, and innovative entrepreneurship, but it is unlikely to become the norm in the United States without substantial public investment and transparent political commitment.

It is also the case that the United States may be at a structural disadvantage compared to other nations

FIGURE 1T GASOLINE PRICE VS. PURCHASING POWER



Source: World Bank; International Energy Agency



currently pursuing aggressive deployment of grid-enabled vehicles. Today, there are more than 2,000 electric utilities and 50 state utility regulators in the United States—compared to just one or a handful of utilities and a single regulator in many other nations. Building a coherent regulatory framework and uniform standards across this vast network will be a daunting challenge.

In China, electrification has been identified as a national priority for addressing urgent energy security and environmental sustainability issues. In Appendix One of this Roadmap, an overview of current government policy in China details the attention that GEVs are currently receiving in that nation. However, it is worth noting here that there are only 30 cars on the road for every 1,000 Chinese citizens compared to 844 for every 1,000 in the United States.⁸² Americans have a distinct and well-defined perception of the automobile, and we have built much of our country around the concept of mobility. The average person in China has not yet attached any specific value or conception to an internal combustion engine versus an electric drivetrain. Without preconceptions of desired performance or range, Chinese consumers figure to be much quicker adopters of affordable electric vehicles.

The cost of gasoline represents perhaps the greatest challenge to U.S. electrification efforts. High fuel taxes implemented in the wake of the 1970s oil crises have altered European and Japanese perceptions about the affordability of oil. In economic terms, these nations have internalized the external costs of oil dependence, and markets have responded. Consumer demand for highly efficient vehicles is much higher in these regions than in the United States, and on-road fuel efficiency is therefore also higher. Additionally, extensive public transportation options have grown up to further supplant the need for oil. As a result, oil demand in the European Union peaked at 15.9 mbd in 1979 and has oscillated between 13 mbd and 15 mbd since.⁸³ Japanese demand peaked at 5.8 mbd in 1996 and has steadily declined since.⁸⁴

The relatively low price of gasoline in the United States means that the payback period for a GEV is significantly higher than in other industrialized nations, and the incentive for consumers to adopt the new technology is correspondingly lower. A higher, equitable, and sustained gas tax is arguably the most transparent and direct policy path to assist GEV market penetration, which would under a range of scenarios provide benefits to taxpayers far in excess of the cost. However, the substantial likelihood of a rapid repeal of such taxes in the early years after enactment for political reasons, as well as the political difficulties of enacting a gas tax increase at a level that would have a dramatic impact, argues for a GEV deployment plan that assumes gas taxes at the current level.

Despite these structural challenges, electrification of transportation can succeed in the United States. In order for electrification to deliver on its full promise, however, the United States must commit to grid-enabled vehicles as the tactical core of a comprehensive oil abatement strategy. In sum, the federal government must choose electrification as a dominant national strategy for improving energy security. Fueling 75 percent of VMT with electricity by 2040 will place the nation on a path to stronger economic growth, improved competitiveness, and enhanced security. But this will not happen unless the government decides to help make it happen.

82 Id., Tables 3.4 and 3.5 at 3-8.

83 BP Statistical Review 2009, Oil Consumption, at 11.

84 Id.

1.5 National Imperative



For electrification to deliver on its full promise, the U.S. must commit to GEVs as the tactical core of a comprehensive oil abatement strategy. This may raise issues of government intervention in the marketplace. However, the total costs of oil dependence are so overwhelmingly damaging to the national interest that an alternative pathway is urgently needed.

WHY GOVERNMENT SHOULD MAKE A CHOICE

The notion of committing to electrification as the core of the nation's efforts to reduce oil dependence raises an important question: should government choose a specific technology path? In light of the significant costs of American oil dependence, action is clearly needed. Two basic options exist for lawmakers. The first is to internalize the external costs of oil dependence. This could be accomplished with significantly higher fuel prices, which in turn would drive consumer demand for alternative technologies, a choice lawmakers have been unwilling to make since the rise of OPEC. The second option is to provide support for an alternative technology.

Higher fuel prices could help to spur technological development in the American automotive industry. As noted earlier, this strategy has had a meaningful impact on consumer choices when it has been pursued by other industrialized nations. The challenge for the United States in adopting a gasoline tax today is that significantly higher prices would be required to achieve behavioral change. Given the current economic climate, a sudden rise in gasoline prices is probably not politically feasible. Governments in Europe and Japan introduced petrol taxes over the course of a number of years, which allowed consumers and the economy time to adjust. Given the magnitude of the current threat from oil dependence, pursuing a similar strategy in the United States would, in any case, need to be undertaken simultaneously with other policy options.

There are specific reasons that electrification of transportation deserves concentrated government support. As noted above, electrification has a range of advantages over the current petroleum-based system that will markedly improve American energy security. But it is also the case that electrification is a more sound strategy to fundamentally transform our transportation sector than any other existing alternative. Moreover, the investments required to spur widespread adoption of grid-enabled vehicles will likely generate spillover effects that will improve the electric power sector, already an integral part of the American energy system. Finally, electrification of transportation represents the next great global manufacturing industry, with the potential to bolster economic growth and create American manufacturing jobs.



1.5.1 Electrification is Superior to Alternatives

Meeting U.S. energy needs in the future will require a balanced portfolio of fuels and technologies across all sectors of the economy. Electrification can transform the light-duty fleet and sharply reduce oil dependence.

Current federal policy provides support to a range of fuels designed to displace petroleum as the dominant fuel in the U.S. transportation system. Electrification, though, offers the fuel diversity, price stability, and emissions benefits needed to meaningfully increase U.S. energy security. Instead of scattered, inconsistent federal support for a wide variety of alternatives, what is required is a coherent, focused strategy designed to radically drive down oil consumption in the light-duty fleet. Part of this strategy must be the acknowledgment that other alternatives, while having value, cannot ultimately revolutionize America's light-duty fleet and end oil dependence.

BIOFUELS

Over the past several years, a number of policies have been put in place to spur production of biofuels—most notably corn ethanol—in the United States. Biofuels represent 5 percent of U.S. marketed fuel. Most biofuels consumed in the United States are produced domestically, which has a positive impact on the trade deficit and helps to create jobs. Moreover, because they

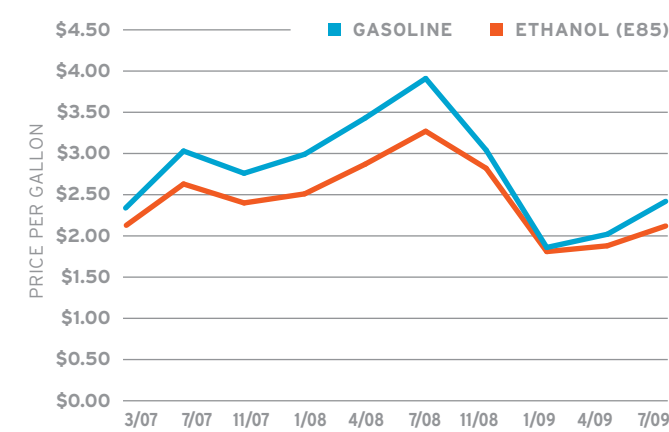
represent an additional source of liquid fuel, biofuels have also helped the global oil market increase total liquid production capacity in recent years. Therefore, whatever progress is made towards the deployment of grid-enabled vehicles in the medium term, biofuels will have an important role to play in helping to meet global demand for energy. Advanced biofuels will also play a role in offsetting oil consumption in the shipping and aviation industries.

However, biofuel prices tend to track oil price volatility closely. This is because the market price is determined by the marginal price of adding another barrel of liquid fuel, and the extra barrel comes from the global oil market. Therefore, when gasoline rises to \$4 per gallon, so does ethanol (adjusted to account for its lower energy content),⁸⁵ when gasoline falls to \$2 per gallon, so does ethanol. And when the price of gasoline falls below the marginal cost of producing ethanol, production of ethanol declines.

NATURAL GAS

Domestic natural gas supplies are plentiful, and recent advancements in the recovery of natural gas resources from unconventional reservoirs like shale gas, coal bed methane, and tight gas sands have led to widespread consensus that undiscovered technically recoverable reserves are now well in excess of 1,000 trillion cubic feet (TCF).⁸⁶ Consuming natural gas emits about 30 percent less CO₂ than oil and 45 percent less than coal on an energy equivalent basis.⁸⁷ These factors have generated considerable interest in expanding the role

FIGURE 1U PRICES OF GASOLINE AND ETHANOL (E85)



Source: DOE, EIA

⁸⁵ In fact, biofuels may sell at a slight discount even after adjustment for its lower energy content to account for the fact that drivers using biofuels will have to refill their tanks more frequently imposing some degree of inconvenience on the driver.

⁸⁶ DOE, EIA, Natural Gas, "How Much Natural Gas Is Left," available at www.tonto.eia.doe.gov/energyexplained/index.cfm?page=natural_gas_reserves.

⁸⁷ Department of Energy, Energy Information Administration, Natural Gas Issues and Trends, at 58 (Table 2)(1999).

of natural gas in the U.S. energy mix in general and the transportation sector in particular.

However, depending on a single fuel for transportation would not appreciably alter the fundamental problem with the existing paradigm. The advantages of fuel diversity provided by electrification are critical from an energy security perspective. At the same time, using natural gas in the light-duty fleet would require a significant expansion of distribution and refueling infrastructure. Electrification would also require infrastructural upgrades, but of a very different—and significantly less substantial—nature.

Nevertheless, natural gas could be used successfully in fleet vehicles, particularly those that can be centrally refueled, including taxis, buses, specialized harbor and airport vehicles, and refuse-collection vehicles. There are also a number of other high-value applications for natural gas in the current U.S. energy system, and the benefits of any expansion of natural gas use must be weighed against its use in other sectors. The most efficient use of natural gas is in large-scale, dispatchable

electricity generation for baseload, intermediate, and peak-load plants and to firm up intermittent renewables. In fact, if the electricity from 1,000 cubic feet of natural gas burned in a current generation power plant were used to fuel an electric vehicle, it would provide enough energy to travel 457 miles. The

same 1,000 cubic feet burned in a current generation natural gas vehicle would only provide enough energy to move 224 miles.⁸⁸

HYDROGEN

Like GEVs, hydrogen-powered vehicles are electric drivetrain vehicles whose electricity is obtained from a fuel cell instead of a battery. In the sense that both vehicles use electric drivetrains, they share many components. At some point in the future, as fuel cell



2004 Ford hydrogen fuel cell vehicle.

technology progresses and the cost of fuel cells fall, hydrogen vehicles may be a successor or supplement to battery-powered electric vehicles.

Commercialization of hydrogen-fueled vehicles, however, faces several obstacles that are far more significant than those facing battery-powered grid-enabled vehicles. First, the cost of hydrogen fuel cells is currently in excess of the cost of a comparable battery cell. Second, reliance on hydrogen would require the construction of an entirely new infrastructure to distribute it to consumers. At the same time, there is no clear ability to manufacture sufficient quantities of hydrogen to fuel the automotive fleet. And perhaps the largest obstacle to the development of a hydrogen-fueled light-duty fleet is the fact that hydrogen itself is much more expensive than electricity, and likely always will be.

Given the commonality between the vehicle designs, and the possibility of converting grid-connected electric vehicles to hydrogen fuel cell vehicles by replacing batteries with fuel cells, electrification of the light-duty vehicle fleet is not incompatible with the deployment of hydrogen fuel cell vehicles at some point in the future. Whether we ultimately move from batteries to fuel cells to power electric drivetrain vehicles will depend on fuel cell development, their relative efficiencies, and their cost.



1.5.2 Infrastructure as a National Priority

Grid-enabled vehicles will require access to public charging equipment and will frequently interface with the electric power sector. These requirements present the United States with an opportunity to invest in a 21st century transportation infrastructure.

Electrification may also present the United States with the opportunity to invest in a 21st century transportation infrastructure. Advanced infrastructure networks are essential to achieving sustainable economic growth and development over the long term. Infrastructure is a national priority that not only ensures global competitiveness, but also can help countries meet environmental challenges. Ensuring the resilience of national infrastructure is also vital to long-term national security. Transportation, communication and energy infrastructure have provided a platform for more than a century of rapid progress in the United States. However, without adequate and appropriate infrastructure investment, American industries will soon struggle to compete in the global marketplace.

The United States has in the past launched grand infrastructure projects that proved vital to the future health, growth, and stability of the economy. The transcontinental railroad in the 1800s, the interstate highway network in the 1950s, and the electric power

grid throughout the 20th century are a few key examples. In each of these cases, Americans benefited by enabling and supporting transportation and industrialization across the country.

Today, years of delayed maintenance, chronic underfunding and lack of modernization have left Americans with an outdated and failing infrastructure that is unable to meet their needs. This endangers the future prosperity of the nation and has a direct effect on economic competitiveness. Some current estimates suggest that the United States will need to invest \$75 billion over the next five years to update electric generation and transmission infrastructure alone.⁸⁹ Though power demand is expected to rise more than 23 percent by 2030, only incremental progress has been made since 2005.⁹⁰ Efforts at reinforcing the energy grid through further investment in generation, transmission and distribution have been stymied by local opposition and an onerous permitting process.

In this context, the construction of a national electrified transportation network can be thought of as the cornerstone of an intense effort to modernize both America's electrical grid and its transportation sector. Widespread use of electric vehicles will require the substantial deployment of public charging infrastructure along highways and in cities. It will also require enhancing the intelligence, robustness, and flexibility of the electric power sector, particularly at the distribution level. This kind of massive infrastructure project has the potential to once again fundamentally transform our transportation system.



An aerial view of a clover leaf interchange on the U.S. interstate highways.

⁸⁸ A PHEV is assumed to get 4 miles per kWh. The heat rate of combined-cycle natural gas turbine is assumed to be 7,000 Btu per kWh. A 20 percent transmission loss was factored in. CNG vehicle is assumed to get 28 miles per gallon of gasoline equivalent (GGE), and there are 124.8 cubic feet of natural gas per GGE.

⁸⁹ American Society of Civil Engineers, "2009 Report Card for America's Infrastructure," at 132, available at www.infrastructurereportcard.org/report-cards, last accessed 2009.09.14.

⁹⁰ AEO 2009, (Supplemental Tables, Table 10: Electricity Growth 2009-2030).

SCALE AND IMPACT
By using existing technology and infrastructure, GEVs promise greater scale and impact than alternative fuels.

1.5.3 Opportunity Costs

Stringent CO₂ emissions standards and high fuel prices have contributed to rapid developments in the global GEV industry. The United States faces the very real risk of being left behind in the next global industry.

In addition to the direct costs of failing to address U.S. oil dependence, there are less direct but equally substantial costs associated with failure to move aggressively to support electrification. In particular, the United States is currently on a path to be at best a second-tier participant in the emerging global market for GEVs and their component parts. Throughout the electrification value chain, new markets are rapidly developing in Europe and Asia—in battery technology in particular—and the United States is likely to forfeit the income, manufacturing capacity, jobs, and economic growth associated with these markets if the status quo approach remains in place.

Ingrained structural advantages and favorable public policies in Asia and much of the industrialized world have laid the groundwork for electrification, and the global marketplace is developing rapidly.

The global market for large format lithium-ion batteries could reach \$10 to \$15 billion by 2015.

Meanwhile, the lack of a long-term regulatory framework supporting electrification has arguably already been costly for the U.S. economy. Of the top eight producers of lithium-ion batteries in the world, accounting for 88 percent of the market, none are headquartered in the United States (all are based in East Asia).⁹¹ Currently, no large-format batteries are manufactured and assembled in the United States at scale. While the global market for advanced batteries was only \$900 million in 2008, Deutsche Bank recently forecast the global market for large format lithium-

ion batteries to reach \$10 to \$15 billion by 2015.⁹² By comparison, the market for lithium-ion batteries in consumer products—laptops, cell phones etc.—is currently estimated at roughly \$7 billion annually.

In fact, the consumer electronics industry could potentially be a harbinger of the fate of the automotive industry. Unwilling to make the large investments required to develop manufacturing capacity that offers small returns, U.S. businesses simply allowed almost all consumer electronics production to migrate to Asia. The electric vehicle, with its high electronics content and expected leaps in connectivity looks substantially more like a consumer electronics product than cars ever have before. It is not unreasonable to envision a scenario where Asian firms quickly begin to dominate this industry as well.

As the rest of the world pursues electric vehicles, U.S. industry faces the very real danger of being left behind. Part of U.S. automakers' hesitancy may simply be the financial requirements of a transition to GEVs. As the domestic OEMs struggle to gain viability after two bankruptcies, the capital required to re-tool an entire industry is largely unavailable. Yet, the United States can ill afford to lose another entire industry. A 2002 study estimated the value of the U.S. automotive value chain at \$432 billion.⁹³ This study did not include the compounding value of all the tertiary service industries that rely on the automotive industry for their health. Although the costs associated with developing a vibrant electric vehicle industry present an obstacle, the cost of doing nothing, at the risk of giving up the domestic auto industry, is even higher.

1.6 Electrification Policy



The United States has a history of intermittent public policy support for vehicle electrification dating back to the 1970s. In general, however, the nation has lacked any consistency in its regulatory and fiscal commitment to electric vehicles.

ELECTRIC AND HYBRID VEHICLE RESEARCH, DEVELOPMENT, AND DEMONSTRATION ACT OF 1976

In the 1970s, successive oil shocks first alerted most Americans to the dangers of oil dependence. Motivated by the increasing costs of importing oil, Congress overrode a veto by President Gerald Ford and enacted the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976.⁹⁴ Its objective was to “expedite electric vehicle commercialization through a program of research and development, large-scale demonstrations, and financial incentives to developers and producers.”⁹⁵

The legislation required the Energy Research and Development Administration (ERDA) to purchase several thousand GEVs and hybrid electric vehicles (HEVs) between 1978 and 1982.⁹⁶ By most accounts, the program was a failure. Over the six years between 1976 and 1982, the Department of Energy spent more than \$717 million, allocating \$509 million for research and development and \$148 million for demonstration activities.⁹⁷ At the program's conclusion, the Government Accountability Office (GAO) found that very little potential existed for widespread EV commercialization and argued that congressional funding should be focused solely on battery research and development.⁹⁸

The design of the program failed to make the distinction between field test and demonstration, an error that doomed it from day one. Congress and DOE aimed to diffuse 10,000 GEVs in various fleet demonstrations,⁹⁹ despite the fledgling state of vehicle battery technology. Essentially, it was a field test and demonstration project rolled together with little opportunity for learning-by-doing. The goal of demonstrating 10,000 GEVs was highly unrealistic in light of the existing economic and technological challenges.

Another obstacle to the goal of GEV market penetration, in the opinion of the GAO, was the lack of financial involvement by major U.S. automakers. The establishment of a self-sustaining electric vehicle industry was infeasible because no major automaker made a financial commitment to production on a large scale.¹⁰⁰ Only “small, fragile companies” that were heavily dependent on government subsidized sales committed to manufacturing GEVs.¹⁰¹ After observing this lack of commitment in the private sector, DOE revoked funding for a cost-sharing proposal that would assist automakers in their developmental and commercialization activities.¹⁰²

By 1982, it was clear that the ERDA program was a failure.¹⁰³ Despite important initial advances in battery technology made possible by the legislation, at its closure President Ford's message in 1976 rang true: “It is simply premature and wasteful for the fed-

94 John T. Woolley and Gerhard Peters, *The American Presidency Project* [online]. Santa Barbara, CA: University of California (hosted), Gerhard Peters (database), available at www.presidency.ucsb.edu/ws/?pid=6329, last accessed on October 22, 2009.

95 United States General Accounting Office, “Electric Vehicles: Limited Range and High Costs Hamper Commercialization,” at i. (March 1982).

96 National Research Council, *Energy Research at DOE: Was it Worth It?*, National Academies Press (2001).

97 In 2008 dollars. United States General Accounting Office, “Electric Vehicles: Limited Range and High Costs Hamper Commercialization,” at 3. (March 1982).

98 Id.

99 Lefevre, Stephen R., *Using Demonstration Projects to Advance Innovation in Energy*, Public Administration Review, at 483-90 (November/December 1984).

100 Id. at 26.

101 Id.

102 United States General Accounting Office, “Electric Vehicles: Limited Range and High Costs Hamper Commercialization,” at 27. (March 1982).

103 Id.

91 Pillot, Christophe, “Main Trends for the Rechargeable Battery Market Worldwide 2007-2015,” *Advanced Battery Technologies*, at 4 (July 1, 2008).

92 Deutsche Bank, *Electric Cars: Plugged In*, at 4 (June 9, 2008).

93 McAlinden, Sean P. and Andrea, David J., “Estimating the New Automotive Value Chain,” *Center for Automotive Research Altarum Institute*, (November 2002).

eral government to engage in a massive demonstration program—such as that intended by the bill—before the required improvements in batteries for such vehicles are developed.”¹⁰⁴

CALIFORNIA'S ZERO EMISSIONS VEHICLE MANDATE AND THE EVI

General Motors' EV1, the most well-known of a number of electric vehicles that appeared on California's roads in the late 1990s, was the result of the Zero Emissions Vehicle (ZEV) Mandate of 1990, in which the California Air Resources Board (CARB) required vehicle manufacturers to sell a certain percentage of vehicles with zero emissions by 1998 if they wished to sell any cars at all in California.¹⁰⁵ The failure of this program remains the subject of much controversy. What is clear, how-

ever, is that despite some apparent consumer demand among niche Californian early adopters, the program unambiguously failed.

The 1990 ZEV mandate passed by CARB was actually just one provision within a large and complex package of rules called the Low Emission Vehicle and

Clean Fuels regulation, later known as LEV I.¹⁰⁶ CARB defined a “zero emissions vehicle” as one from which no tailpipe pollutants were emitted from the car's powertrain. The top seven automakers, in terms of California sales, would be required to produce and sell a minimum of 2 percent ZEVs beginning with the 1998 model year, amounting to about 20,000 GEVs.¹⁰⁷ The initial requirement of 2 percent ZEVs in 1998 would

rise to 5 percent in 2001 and 10 percent in 2003.¹⁰⁸ Inspired by GM Chairman Roger Smith's speech following the demonstration of the all-electric Impact, regulators hoped that this ramp-up would result in the market taking off with no further regulatory assistance required after 2003.¹⁰⁹

In response to the mandate, the federal government and major automakers formed the United States Advanced Battery Consortium (USABC) in 1991.¹¹⁰ Increased federal funding and a matching industry share created a rich program for battery development, with short-term goals for meeting California's mandate and long-term goals for designing lithium-based batteries. In 1993, USABC was folded into the Partnership for a New Generation of Vehicles (PNGV).¹¹¹

However, at the time that ZEV mandates were being implemented, battery cost and power remained a substantial obstacle. In 1990, lead-acid batteries were the only commercial possibility, but they had an energy density of only about 25 Wh/kg (versus up to 150 Wh/kg for today's lithium-ion batteries). The existing prototypes, such as the Ford-GE ETX-1, had maximum ranges of around 100 miles and could not exceed speeds of 60 miles per hour.¹¹²

GM launched its GEV deployment through a 50-vehicle PreView Program between 1994 and 1996. Despite reports that GM hoped the test would reveal little interest in electric cars, advertising in the Los Angeles and New York City areas received an overwhelming response, with more than 10,000 calls by volunteers in each area.¹¹³ In total, 700 Americans in 11 cities experienced a 2-week test drive.¹¹⁴ With an 80-mile range, air-conditioning, radio, and a 4-speaker

108 California Air Resources Board, Zero Emissions Vehicle Legal and Regulatory Activities, “ZEV Program Timeline,” available at www.arb.ca.gov/msprog/zevprog/background/background.htm, last accessed on October 22, 2009.

109 Collantes, Gustavo Oscar, “The California Zero-Emission Vehicle Mandate: A Study of the Policy Process, 1990-2004,” Institute of Transportation Studies, University of California, Davis, 2005, p. 35.

110 Commission on Engineering and Technical Systems, Effectiveness of the United States Advanced Battery Consortium as a Government-Industry Partnership, Washington, D.C., National Academies Press, 1998.

111 National Research Council, Energy Research at DOE: Was It Worth It?, Washington, D.C., National Academies Press, 2001.

112 Westbrook, Michael H., The Electric Car: Development and Future of Battery, Hybrid and Fuel-Cell Cars, Institution of Electrical Engineers Power and Energy Series 38, London: The Institution of Engineering and Technology Press, at 25 (2001).

113 Wald, Matthew L., “Expecting a Fizzle, G.M. Puts Electric Car to Test,” The New York Times, January 28, 1994.

114 Shnayerson, Michael, The Car that Could: The Inside Story of GM's Revolutionary Electric Vehicle, Random House (1996).

Through public policy, the U.S. was able to reduce the oil intensity of the economy by 35% from 1972–1985.



Measuring tailpipe emissions in a California Smog Inspection Station; the state has been a leader in clean air and pollution control for years.

stereo system, the vehicles met the needs of most drivers. The consumer feedback was considered extremely positive, with 80 percent of participants satisfied with the range of their electric vehicles.¹¹⁵ Concern tended to be over cost rather than range.¹¹⁶ In 1996, GM began leasing the EV1 at select Saturn dealerships in Arizona and California.¹¹⁷

Other car companies quickly followed suit with electric light-duty trucks and SUVs, including the Ford Ranger pickup, the Honda EV Plus, the Toyota RAV4 EV, the Nissan Altra EV, the Chevrolet S-10 compact pickup, and the Chrysler EPIC minivan.¹¹⁸ In 1998, GM replaced the EV1's lead-acid battery with a nickel metal-hydride battery, increasing the car's range to 160 miles. Despite long wait lists for the vehicles, only 800 EV1s were made available for leasing in California and Arizona.¹¹⁹ Arizona offered free registration for electric vehicles and credits bringing the lease payments down to about \$640, compared to \$480 in Los

Angeles.¹²⁰ By 2000, there were a total of around 2,300 electric vehicles on the road in California.¹²¹

Though most owners of the vehicles charged at home, in 2000 there were 400 public charging stations with 700 individual chargers. These were viewed as important to consumer acceptance, and all were funded by the government and electric utilities. A few private actors began to get into the business, as well, such as Costco. CARB identified the lack of uniform standards for equipment as the project's largest problem, in part because the automakers were unwilling to cooperate to standardize the charging process, so the cars made by different automakers charged at different voltages and used incompatible plugs.¹²²

Despite the infrastructure set backs, a 2000 CARB Staff Report concluded that “California has made significant technological progress toward its zero emission objectives...illustrating that ZEVs can be built and deployed. There are a variety of attractive ZEV platforms. Also, their respective characteristics meet a wide range of market applications including fleets, small businesses and private commuting. While electric vehicle range is limited and recharging times are

104 John T. Woolley and Gerhard Peters, The American Presidency Project [online]. Santa Barbara, CA: University of California (hosted), Gerhard Peters (database), available at www.presidency.ucsb.edu/ws/?pid=6329, last accessed on October 22, 2009.

105 California Air Resources Board, Zero Emissions Vehicle Legal and Regulatory Activities, “ZEV Program Timeline,” available at www.arb.ca.gov/msprog/zevprog/background/background.htm, last accessed on October 22, 2009.

106 Collantes, Gustavo Oscar, “The California Zero-Emission Vehicle Mandate: A Study of the Policy Process, 1990-2004,” Institute of Transportation Studies, University of California, Davis (2005).

107 Brown, Mark B., The Civic Shaping of Technology: California's Electric Vehicle Program, Science, Technology, & Human Values, Vol. 6, No. 1., at 70.

115 Brown, Mark B., The Civic Shaping of Technology: California's Electric Vehicle Program, Science, Technology, & Human Values, Vol. 6, No. 1 at 69 (2001).

116 Id.

117 Siuru, Bill, “5 Things you Need to Know About the GM EV1” GreenCar.com, July 3, 2008, available at www.greencar.com/articles/5-things-need-gm-ev1.php, last accessed on October 22, 2009.

118 Anderson, Curtis D., Electric and Hybrid Cars: A History, McFarland & Company, at 49 (2004).

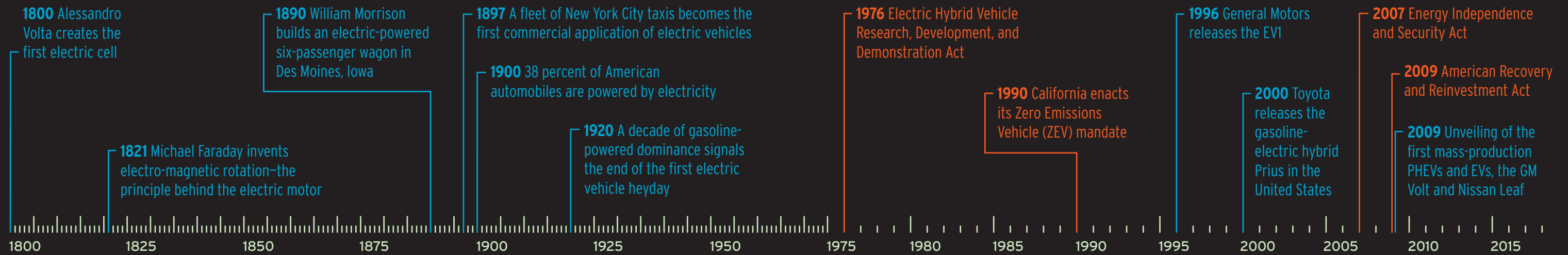
119 Chan, Sue, “GM Pulls Plug On Electric Car,” CBS Evening News Online (March 11, 2003), available at www.cbsnews.com/stories/2003/03/11/eveningnews/main543605.shtml, last accessed on October 22, 2009. Costs expressed in 2008 dollars.

120 “EV1 on Sale Dec. 5; Leases Range from \$480 to \$640,” Ward's AutoWorld (November 1, 1996), available at wardsautoworld.com/ar/auto_ev_sale_dec/, last accessed on October 22, 2009.

121 National Energy Technology Laboratory (NETL), “Battery-Powered Electric and Hybrid Vehicle Projects to Reduce Greenhouse Gas Emissions: A Resource Guide for Project Development,” Science Applications International Corporation (July 2002).

122 California Air Resources Board, “2000 Zero Emission Vehicle Program Biennial Review,” Staff Report (August 7, 2000).

FIGURE 1V U.S. ELECTRIC VEHICLE TIMELINE



long, ZEVs are in everyday use in many different circumstances across the state. All evidence and testimony points to the fact that those who are using today's EVs are very pleased with their performance.¹²³

In 1996, the ZEV guidelines were revised. Requirements for 1998 were eliminated in exchange for 10 percent ZEV sales in 2003. The revised standards allowed hybrid, natural gas and “low speed vehicles” (LSVs), which are closely related to golf carts and intended for neighborhood use, to contribute to the program's goals. Finally, after further objections from various stakeholders, a U.S. District Court judge issued an injunction in 2001 preventing amendments to the ZEV mandate. CARB could only respond by delaying ZEV requirements.¹²⁴ Over the next decade, these standards would continue to evolve. In the latest 2008 ZEV revisions, CARB voted to require production of 25,000 ZEVs by each manufacturer between 2012 and 2014, a number which can be reduced if more PHEVs are made available.¹²⁵ The requirement for ZEVs, however, ended in 2003, with more than 4,400 GEVs

having been deployed in California since 1996.¹²⁶ GM is reported to have simply given away over a thousand golf cart-like vehicles to meet the mandate.¹²⁷

The ZEV mandate was revolutionary in environmental public policy in that it sought to simultaneously change vehicle technology and consumer behavior without substantial federal or state financial support. As in 1976, electric vehicle technology and national sentiment were probably unprepared for the ZEV mandate. Today, however, the situation is different. Just after testifying to Congress about his company's need for a financial bailout in late 2008, Rick Wagoner, the longtime GM CEO, said in an NPR interview that discontinuing the EV1 as well as the larger focus on electric powertrains and fuel economy was his “biggest mistake.”¹²⁸

PARTNERSHIP FOR A NEW GENERATION OF VEHICLES

The ZEV mandate was the direct impetus for the Department of Energy's largest electric vehicle program to date. At the same time as California was implementing

its mandate, DOE was funding a number of private firms and industry groups, most importantly the United States Advanced Battery Consortium (USABC), a public-private research program for building batteries for electric vehicles. USABC was a partnership between DOE and USCAR, an association of Ford, General Motors, and DaimlerChrysler.¹²⁹ In 1992, DOE decided that advanced battery technology, systems engineering and power electronics were sufficiently developed to make hybrid-electric vehicles (HEVs) competitive with conventional vehicles. Propelled by California's ZEV decision, DOE in 1993 combined all existing programs into the Partnership for a New Generation of Vehicles (PNGV). Despite the technological challenges, the DOE-USCAR work laid the foundation for influential market players, including major Japanese companies, to develop today's batteries.¹³⁰

Though no new funding was appropriated, the program was unprecedented in presenting a public-private partnership with a coherent set of strategic goals for massively improving fuel efficiency. Seven federal agencies, including the Department of Defense, collaborated with DOE. The government actors would focus on the basic, more long-term R&D, while the automakers (USCAR) would work on bringing technologies to

rapid deployment. Other partners included national laboratories, universities and automotive suppliers.¹³¹ The program had three stated goals:

1. Improve American automotive manufacturing competitiveness;
2. Rapidly introduce new technology developed by PNGV research and development into retail vehicles; and
3. Produce prototype midsize sedans rated at 80 miles per gallon (mpg) by 2004.¹³²

The first and second goals were achieved quite successfully. A review board determined that while USCAR did improve manufacturing capabilities, the automotive suppliers experienced a greater effect, particularly in producing lightweight materials at lower cost. PNGV efforts reduced the cost of lightweight aluminum, magnesium, and glass-fiber reinforced polymer components to well under half the cost of steel, which—along with the invention of carbon foam and near-frictionless carbon coating—dramatically reduced vehicle weight and improved efficiency. The researchers invented and demonstrated a number of clean-diesel technologies and improved the efficiency and power-to-weight ratio of power electronics while reducing their costs 86 per-

123 Id.

124 California Air Resources Board, “2003 Zero Emission Vehicle Program Changes,” Fact Sheet (March 18, 2004), available at www.arb.ca.gov/msprog/zevprog/factsheets/2003zevchanges.pdf, last accessed September 14, 2009.

125 California Air Resources Board, “ARB passes new ZEV amendment,” News Release, March 27, 2008, available at www.arb.ca.gov/newsrel/nr032708b.htm, last accessed September 14, 2009.

126 Bedsworth, Louise Wells and Margaret R. Taylor, “Learning from California's Zero-Emission Vehicle Program,” California Economic Policy, Public Policy Institute of California, Vol 3 No. 4, (Sept. 2007).

127 Ellis, Michael, “GM to Give Away Thousands of Electric Vehicles,” Reuters, August 14, 2002.

128 National Public Radio, “GM CEO Outlines Company's Plans,” All Things Considered Broadcast, December 4, 2008, available at www.npr.org/templates/story/story.php?storyId=97826113&ft=1&f=1006, last accessed September 14, 2009.

129 National Research Council, “Energy Research at DOE: Was It Worth It?” National Academies Press (2001).

130 Commission on Engineering and Technical Systems, Review of the Research Program of the Partnership for a New Generation of Vehicles, Washington, D.C.: National Academies Press (1994).

131 Id. at 10.

132 Gravatt, Claude C., “Testimony before the Committee on Commerce, Science and Transportation,” U.S. Senate, (December 6, 2001), available at www.ogc.doc.gov/ogc/legreg/testimon/107f/gravatt1206.htm, last accessed September 12, 2009.



President George W. Bush, with Speaker of the House Nancy Pelosi (2nd L), Secretary of Energy Samuel Bodman (L) and other lawmakers, signs the Energy Independence and Security Act of 2007 during a ceremony at the U.S. Department of Energy in Washington, D.C.

cent between 1995 and 2001. New laser welding, hybrid material recycling from scrap standardization, and new die software were also developed.¹³³ PNGV met its second goal when a number of these technologies were used in production lines. For example, lightweight aluminum was incorporated into the 2000 Lincoln LS, reducing the car's weight by 188 pounds. Similarly, the Jeep Wrangler and Chevrolet Silverado benefited from composite materials.¹³⁴

Goal three had many components, including meeting stringent emissions standards while maintaining the comfort and power to which consumers are accustomed. DaimlerChrysler produced the Dodge ESX3, Ford unveiled the Prodigy, and GM developed two versions of its Precept concept car. All were diesel-electric hybrids. All three of the prototypes were rated at above 72 miles per gallon, but failed to meet the emissions requirements of the goal.¹³⁵

As of 2001, according to the Seventh Report of the PNGV Standing Committee at the Transportation Research Board (TRB), the next element of goal three

was for each company to create production prototype cars by 2004. The report detailed that all three companies were in planning stages.¹³⁶ Separately, the three USCAR partners had announced in 2000 plans for at-scale light truck and SUV hybrid-electric production by 2004.¹³⁷ However, in 2001 the Bush administration transformed the program into FreedomCAR, which conducts R&D in high-risk and long-term technologies like advanced hydrogen fuel cells (although some battery research continues).¹³⁸ The PNGV program can claim some direct responsibility for the release of hybrid vehicles by the Big Three in the mid 2000s, but these vehicles have not been as efficient as hoped.

THE ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

The Energy Independence and Security Act of 2007 (EISA) was an important piece of legislation with respect to promoting GEV deployment. EISA established a Near-Term Transportation Sector Electrification Program and authorized \$95 million per year in grants between 2008 and 2013, with an emphasis on large-scale electrification projects.¹³⁹ A second program, the Plug-in Electric Drive Vehicle Program, further authorized DOE to disperse \$90 million per year between 2008 and 2012 in grants to states and localities to encourage the use of plug-in electric drive vehicles or other emerging electric vehicle technologies.¹⁴⁰

EISA also authorized \$25 billion in loans for Advanced Vehicle Manufacturing Facilities to be allocated to companies wishing to establish or re-equip plants to produce EV components.¹⁴¹ The first approximately \$8 billion of these loans was awarded in June 2009 to Ford, Nissan, and Tesla for \$5.9 billion, \$1.6 billion, and \$465 million respectively. An additional \$529 million went to Fisker Automotive in September

¹³⁶ Id.

¹³⁷ Gravatt, Claude C., "Testimony before the Committee on Commerce, Science and Transportation," U.S. Senate, (December 6, 2001), available at www.ogc.doc.gov/ogc/legreg/testimon/107f/gravatt1206.htm, last accessed September 12, 2009.

¹³⁸ Department of Energy, Energy Efficiency and Renewable Energy Office, "FreedomCAR and Fuel," Vehicle Technologies Program (March 12, 2009), available at www1.eere.energy.gov/vehiclesandfuels/about/partnerships/freedomcar/index.html, last accessed September 12, 2009.

¹³⁹ Energy Independence and Security Act of 2007, at §131(b).

¹⁴⁰ Id., at §131(c).

¹⁴¹ Id. at §136.

¹³³ Id.

¹³⁴ National Research Council, *Energy Research at DOE: Was It Worth It?*, National Academies Press (2001).

¹³⁵ Transportation Research Board, Standing Committee to Review the Research Program for the Partnership for a New Generation of Vehicles, *Review of the Research Program of the Partnership for a New Generation of Vehicles, Seventh Report*, National Research Council, Transportation Research Board, Washington D.C.: National Academy Press, 2001.



2009.¹⁴² It should be noted, however, that though the majority of this award money will be used for vehicle electrification, significant portions of it, especially the amounts allocated for Ford, will also be used for other advanced fuel-saving engine technologies, including direct injection, turbo, and advanced transmissions.¹⁴³

More than 70 other applicants submitted proposals for the loan program, and \$17 billion of loan money remains available (as of October 2009).^{144, 145} The Department of Energy, which is responsible for the management of the loan distribution process, has not indicated when further awards may be announced.

EISA is, perhaps, best-known for directing the Department of Transportation and the Environmental Protection Agency to establish new fuel economy standards. The law calls for a 40 percent increase in fleetwide fuel economy in new vehicles between 2010 and 2020, raising the combined fleet average from 25 miles per gallon to 35 miles per gallon.¹⁴⁶ In May 2009, President Obama announced his intent to further strengthen the new fuel economy standards, requiring overall fleet fuel efficiency for all domestically sold passenger cars to reach 39 miles per gallon by 2016, up from 27.5 miles per gallon today. Light trucks and sport utility vehicles will have to achieve 30 miles per gallon, up from 23.1 miles per gallon today.¹⁴⁷ It is likely that some form of increased hybridization and electrification will be needed to meet such standards; however, the standards alone are not sufficient to drive significant production of grid-enabled vehicles.

¹⁴² Blanco, Sebastian, "Fisker gets \$528.7 million loan from U.S. DOE for Karma, Project Nin," Autblog Green, available at www.autoblog.com/2009/09/22/breaking-fisker-gets-528-7-million-loan-from-u-s-doe-for-karma, last accessed on October 22, 2009.

¹⁴³ See, e.g., Ford Motor Company Business Plan, Submitted to the Senate Banking Committee, December 2, 2008, at 14, available at media.ford.com/images/10031/Ford_Motor_Company_Business_Plan.pdf, last accessed on October 22, 2009.

¹⁴⁴ Office of the Honorable John Dingell, "Entire Congressional Delegation Asks President for Help Creating Green Jobs and Cars of the Future in Michigan," (January 23, 2009), available at www.house.gov/apps/list/press/mi15_dingell/090123delegationletter.shtml, last accessed on October 22, 2009.

¹⁴⁵ Blanco, Sebastian, "Officially, Official: Ford Gets \$5.9b from DOE in ATVMP Funds for 13 Greener Cars," Autblog Green, (June 23, 2009), available at green.autoblog.com/2009/06/23/officially-official-ford-gets-5-9b-from-doe-in-atvmp-funds-for/, last accessed on October 23, 2009.

¹⁴⁶ Energy Independence and Security Act of 2007, at §102.

¹⁴⁷ The White House, "President Obama Announces National Fuel Efficiency Policy," Office of the Press Secretary (May 19, 2009), available at www.whitehouse.gov/the_press_office/President-Obama-Announces-National-Fuel-Efficiency-Policy/, last accessed September 18, 2009.



President Barack Obama signs the American Recovery and Reinvestment Act as Vice President Joe Biden looks on. Obama signed the 787-billion-dollar economic stimulus bill at a ceremony in Denver, Colorado.

THE AMERICAN RECOVERY AND REINVESTMENT ACT OF 2009

The American Recovery and Reinvestment Act of 2009 (ARRA) included additional funding for advanced energy projects, including electric drive vehicles.¹⁴⁸ The Obama administration announced \$2.4 billion in grants for advanced battery and electric drive programs in August 2009.¹⁴⁹ Of these funds, \$1.5 billion was allocated to support battery manufacturing. Another \$500 million was awarded to companies involved in manufacturing the drivetrain components for electric vehicles. The remaining \$400 million was spent on demonstration infrastructure and vehicle projects as well as education and research funding.¹⁵⁰

The ARRA grant funds were quickly appropriated and apportioned. The rapid grant-making occurred because of the urgent nature of the economic crisis. The largest awards within the Electric Drive Vehicle Battery and Component Manufacturing Initiative were granted to Johnson Controls, Inc (\$299 million) and A123 Systems (\$249 million), both in Michigan, to

¹⁴⁸ American Recovery and Reinvestment Act of 2009.

¹⁴⁹ "President Obama Announces \$2.4 Billion in Grants to Accelerate the Manufacturing and Deployment of the Next Generation of U.S. Batteries and Electric Vehicles," White House Press Office, (August 5, 2009), available at www.whitehouse.gov/the_press_office/24-Billion-in-Grants-to-Accelerate-the-Manufacturing-and-Deployment-of-the-Next-Generation-of-US-Batteries-and-Electric-Vehicles/, last accessed on October 22, 2009.

¹⁵⁰ Id.

manufacture advanced batteries and packs for hybrid and electric vehicles. The four next largest grantees, three of which are also based in Michigan, were EnerDel, General Motors Corporation, a Dow/Kokam joint venture, and LG Chem.¹⁵¹

The largest infrastructure piece of the grant announcement was an award that went to the Electric Transportation Engineering Corp (eTec), the charging infrastructure arm of ECotality, to work with Nissan to demonstrate 5,000 of Nissan's 100-mile range LEAF model EVs and deploy roughly 13,000 chargers in pilot programs in five U.S. regions (Portland, Salem, Eugene and Corvallis, OR; Seattle, WA; San Diego, CA; Phoenix and Tucson, AZ; and Nashville, Chattanooga, and Knoxville, TN).¹⁵²

The LEAF, manufactured in Smyrna, Tennessee, had already received \$1.6 billion under the Advanced Technology Vehicle Manufacturing program. The new funding—which, combined with matching shares from regional pilot participants, adds up to nearly \$200 million—will support what Nissan describes as the largest GEV demonstration project ever undertaken, and represents an important stepping stone to larger, more comprehensive demonstration projects employing multiple automakers.¹⁵³ Nissan has announced that the vehicles will be sold in late 2010 and 2011.¹⁵⁴

ARRA also revised electric vehicle tax credits for U.S. consumers. Under the new law, U.S. residents who purchase GEVs will be able to claim a base tax credit of \$2,500 for a vehicle with a battery of at least 5 kWh and \$417 dollars per kWh from 5 upward, capping at an additional \$5,000.¹⁵⁵ The maximum tax credit, there-

fore, is \$7,500. The credit applies to the first 200,000 vehicles per manufacturer.¹⁵⁶

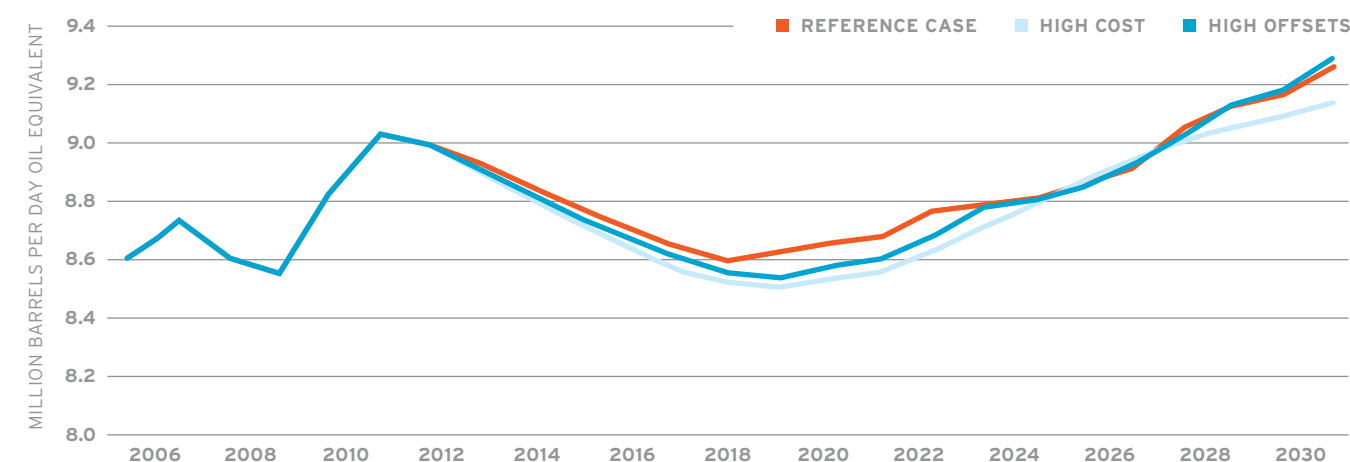
OTHER INITIATIVES

The flurry of federal funding for clean energy projects comes on the heels of state action. Many states with populations supportive of policies that are designed to mitigate greenhouse gas emissions have independently sought to regulate stationary sources of pollution through projects like the Northeast's Regional Greenhouse Gas Initiative, the first mandatory, market-based carbon-trading forum. Federal inertia has also prompted many states to try to regulate mobile emissions sources. Meanwhile, some states have begun to establish low carbon fuel standards, a purportedly technology-neutral way to reduce greenhouse gases.¹⁵⁷

Congress has also begun the process of limiting CO₂ emissions. In July 2009, the House passed the American Clean Energy and Security Act of 2009 (ACES),¹⁵⁸ which, if enacted, would implement a nationwide carbon cap-and-trade program. Such a program, though it may offer benefits in terms of carbon abatement, is unlikely to significantly affect petroleum use. Even assuming a CO₂ permit price of \$70 per ton, the carbon content of a gallon of gasoline would at most reflect an additional 10 cents above baseline forecasts between 2010 and 2020 and an additional 16 cents between 2020 and 2030.¹⁵⁹ These increases are insufficient to compel consumers to purchase more efficient vehicles.¹⁶⁰ The bill does authorize the Department of Transportation in collaboration with the EPA and DOE to set motor vehicle emis-



FIGURE 1W LDV FLEET OIL CONSUMPTION UNDER ACES IN THREE CASES



Source: DOE, EIA

sions standards commensurate with its CO₂ goals.¹⁶¹ These standards would most likely be significantly more aggressive than currently proposed standards, and would, therefore, provide long-term support for highly efficient, low-emissions vehicles.

In addition to emissions requirements, ACES directly addresses GEVs by calling for an Electric Vehicle Infrastructure Plan.¹⁶² Provisions within the bill would require utilities to submit a plan for supporting plug-in electric vehicles, including measures to support battery exchange, fast charging, and other elements. State regulatory authorities would be required to ensure that public charging infrastructure is interoperable with a range of vehicle technologies and to consider measures for allowing utilities to recover costs associated with their plans. The bill would also require the Secretary of Energy to prepare a plan to place grid-enabled vehicles in a number of regions, and would double the amount authorized under the AVTM to \$50 billion.¹⁶³

The provisions within ACES that deal with vehicle electrification represent an important step forward. Beyond simply providing additional funding to automakers and greater incentives to consumers, the bill begins to outline a process for deploying electric vehicles in high concentrations. However, the provisions are not tied to any specific goal for vehicle penetration or future oil abatement. Moreover, the bill stops short of committing to electrification as a dominant strategy, instead increasing government support for a range of technologies, including biofuels. This speaks to the fundamental lack of national commitment to electrification. America's approach today is haphazard and unfocused, without strategic goals to guide policy either in Congress or in the relevant executive departments. Without aggressive and coordinated government policy, GEVs will only marginally penetrate the U.S. market over the next decade.

151 Department of Energy, "Recovery Act Awards for Electric Drive Vehicle Battery and Component Manufacturing Initiative," available at www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf, last accessed on October 22, 2009.

152 Department of Energy, "Recovery Act Awards for Transportation Electrification," available at www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf, last accessed on October 22, 2009; Etec Website, available www.etecevs.com/PHEV-activities/.

153 Nissan USA, "Nissan Supports Electric Vehicle and Infrastructure Project," (August 5, 2009), available at www.nissannews.com/newsrelease.do?jsessionid=6F287FA03857EDF910DB2D36958C1BE0?d=799&mid=1, last accessed September 18, 2009.

154 Nissan, "Nissan's Plan for Zero-Emissions Vehicles Advances with U.S. Department of Energy Loan," June 23, 2009, available at www.nissanusa.com/leaf-electric-car/#/news, last accessed on October 22, 2009.

155 Department of Energy, "Recovery Act - Electric Drive Vehicle Battery and Component Manufacturing Initiative," March 27, 2009, available at www1.eere.energy.gov/vehiclesandfuels/pdfs/de-foa-0000026.pdf, last accessed October 22, 2009.

156 American Recovery and Reinvestment Act of 2009, §1141(a).

157 Galbraith, Kate, "Northeastern States Push Toward Low-Carbon Fuel Standard," *The New York Times*, January 5, 2009; California Air Resources Board, "Low Carbon Fuel Standard Program," available at www.arb.ca.gov/fuels/lcfs/lcfs.htm, last accessed on October 22, 2009.

158 H.R. 2454, The American Clean Energy and Security Act of 2009, as passed by the House of Representatives on June 26, 2009.

159 David Friedman, Director and Senior Engineer at the Union of Concerned Scientists, "Testimony before the House Committee on Energy and Commerce, Subcommittee on Energy and the Environment," (April 24, 2009), available at www.ucsusa.org/assets/documents/clean_vehicles/UCS-House-Energy-and-Commerce-Testimony.pdf, last accessed on October 22, 2009.

160 Congressional Budget Office, "The Estimated Costs to Households from the Cap-and-Trade Provisions of H.R. 2454," (June 19, 2009) (hereinafter H.R. 2454), available at www.cbo.gov/ftpdocs/103xx/doc10327/06-19-CapAndTradeCosts.pdf, last accessed on October 22, 2009.

161 H.R. 2454 at §821.

162 Id. at §121.

163 Id. at §125.

PART TWO

Challenges & Opportunities



2.1 OVERVIEW



2.2 BATTERIES & VEHICLES



2.3 CHARGING INFRASTRUCTURE



2.4 ELECTRIC POWER SECTOR



2.5 CONSUMER ACCEPTANCE



One of over 150,000 gasoline stations in the U.S. Ensuring that GEVs have access to a reliable network of public charging infrastructure is a key challenge to early adoption.

ABSTRACT

Core Challenges

The successful deployment of GEVs faces a range of challenges. Early GEV batteries will have limited range, may take hours to charge, and will add significantly to vehicle cost. Vehicle charging infrastructure is non-existent, and consumers may hesitate to accept new technology.

Yet, each of these challenges can be overcome to achieve widespread, large-scale deployment of grid-enabled vehicles in the near future. Policy support and innovative business models will drive down battery costs and work to deploy adequate charging infrastructure. The electrical grid reaches most corners of the nation, and only upgrades to the last few feet of wire are required to deploy vehicle chargers in mass. The electric power industry has the capacity to generate and transmit most of the power that will be needed to charge GEVs, certainly in the early to middle stages of deployment. Over the long term, smart-grid technology will manage vehicle-to-grid interface while enhancing the overall consumer experience.

2.1 Overview



Despite the progress currently being made in the global electric vehicle market, substantial barriers to widespread vehicle adoption still exist. Overcoming these barriers will require innovative business models and the support of effective public policy.

BATTERIES & VEHICLES

Ongoing battery research is concentrated on developing new chemistries and assessing the performance of batteries under different usage conditions. The focus of much of the battery industry is on producing batteries with high energy and power at a cost most consumers will find compelling. A range of generic estimates for current battery costs centers on \$600 per kWh. The long-term goal for most market participants is closer to \$200 per kWh. The primary drivers of battery cost are high material costs and lack of scale. Battery performance is significantly impacted by the charge cycle and temperature, among other factors.

CHARGING INFRASTRUCTURE

Deploying electric vehicles at scale will require the construction of a network of charging infrastructure, both public and private (home). The costs for public Level II electric vehicle supply equipment (EVSE) are highly dependent upon location, but currently range up to \$5,000 per unit; Level III chargers will be less prevalent, as they will be used for fast charging, but are significantly more expensive. The ability for EVSE and charger owners to recoup these costs will depend on utilization rates and whether vendors are allowed to charge a premium for charging. Entrepreneurship and innovation will surely develop models for profitable operation, but in a country as geographically diverse and as large as the United States, it is difficult to imagine a scenario in which substantial government investment would not be required to assist in laying the backbone of the GEV charging network.

ELECTRIC POWER SECTOR

Managing the interface between the grid—power generation, transmission, and distribution—and the vehicles presents additional complexities. In moving from oil to electricity, we must be deliberate in ensuring the reliability of the U.S. power system. Failure to do so would simply trade one economic vulnerability for another. The current regulatory framework may be inadequate to support widespread GEV adoption, and a set of standards for everything from plugs to outlets to charging stations will be required to ensure uniform operability.

CONSUMER ACCEPTANCE

There remains the question of whether enough consumers will ever be willing to accept the demise of the internal combustion engine and the transition to electricity. The payback periods for GEV ownership will need to be dramatically—and permanently—reduced. And yet, policies designed to discourage oil consumption via price incentives are controversial and politically charged.

2.2 Batteries & Vehicles



GEVs trace their roots to today's familiar hybrids, but represent a significant advancement in efficiency. Therefore, a great deal of current attention is focused on developing grid-enabled vehicles that meet consumer needs. Most such efforts are dedicated to commercializing advanced batteries that provide the power and range expected by drivers.

HYBRID TECHNOLOGY: A BRIEF HISTORY

The battery technology for the next generation of vehicle electrification traces its roots to today's more familiar gasoline-electric hybrid vehicles (HEVs). These vehicles rely on a conventional internal combustion (IC) engine, but supplement certain functions with power from an on-board battery. How much work the battery does depends on its size and the configuration of the drivetrain. In general, the more energy the battery is capable of delivering, the greater the gasoline fuel savings.

HEVs have already enjoyed commercial success as a result of government incentives and high oil prices, though they still only represent a small fraction of total auto sales and an even smaller fraction of vehicles on the road. Hybrids broke into the automotive market at the turn of the century with the introduction of the **Honda Insight** and the **Toyota Prius**. The Honda Insight was first sold in the United States in 1999 and incorporated a mild hybrid system. The first generation of the Honda Insight was sold through model year 2006. After a brief hiatus, the brand was re-launched in 2009 for the 2010 model year. The current version of the Insight is the most inexpensive hybrid vehicle available in North America.

The Toyota Prius has arguably been the most successful hybrid vehicle in the United States and helped to firmly cement Toyota's image in this country as the market technology leader. The Prius was first marketed in the United States in 2001 and was the first production implementation of a full hybrid system.¹ The Prius, like most full hybrids, utilizes two electric motors during operation. The first is essentially a

bolstered starter motor and generator that controls the start/stop functionality of the gas engine and the charging of the battery. The second motor can power the vehicle, typically at low speeds, and works in tandem with the IC engine during acceleration and at highway speeds. The second motor also performs the regenerative braking energy conversion.²

In 2009, Toyota introduced the third generation of the Prius, pricing it competitively with the Honda Insight.³ In Japan, the demand for the new Prius overwhelmed Toyota with reports of up to six-month order backlogs.⁴ In August 2009, the introduction of the new Prius in the United States coincided with government incentives for purchasing efficient vehicles (Cash for Clunkers), which helped push worldwide Prius sales to their highest mark since the beginning of the 2008/2009 recession.

Since the introduction of the Prius and the Insight, Toyota and Honda have each sought to leverage their basic hybrid drive configuration in several other vehicle models. Examples include the **Honda Accord** and **Civic** hybrids; the **Toyota Camry** hybrid; and the **Lexus LS600hL**, **RX 450h**, and **HS 250h** models.^{5, 6}

After the Japanese automakers' initial success with their hybrid programs, a number of U.S. and

2 Id.
 3 "2010 Toyota Prius to Be Priced Competitively With the 2010 Honda Insight," egmCarTech, (April 2, 2009), available at www.egmcartech.com/2009/04/02/2010-toyota-prius-to-be-priced-competitively-with-the-2010-honda-insight/, last accessed on October 22, 2009.
 4 Loveday, Eric. "New Prius is Hot, 180,000 Orders In, 7 Month Waiting Period," AllCarsElectric, (June 22, 2009), available at www.allcarselectric.com/blog/1021624_new-prius-is-hot-180000-orders-in-7-month-waiting-period, last accessed on October 22, 2009.
 5 "Hybrid Cars Guide," available at www.hybrid-cars-guide.com, last accessed on October 22, 2009.
 6 "Lexus Hybrid Vehicles," Lexus, available at www.lexus.com/hybriddrive/index.html, last accessed on October 22, 2009.

1 "Toyota Prius," Speed Ace, available at www.speedace.info/automotive-directory/toyota/toyota_prius.htm, last accessed on October 23, 2009.



European automakers quickly followed suit. Early on, Ford introduced a hybrid version of the **Escape**. Later, the company added the hybrid **Ford Fusion** to its lineup.^{7, 8}

GM soon developed a hybrid architecture, dubbed the "two-mode hybrid." Being late to the game meant GM had to take on the massive hybrid research and development cost in a relatively short time span.⁹ As a result, it chose to enter into a hybrid development partnership with DaimlerChrysler and BMW in order to help defray those costs.¹⁰ The partnership ended with a slew of new vehicle introductions for the 2008 and 2009 model years, including the **Chevrolet Silverado** and **Tahoe** hybrids; the **Cadillac Escalade** hybrid; the **GMC Sierra** and **Yukon** hybrids; the **Saturn Vue** hybrid; the **Dodge Durango** hybrid; the **Chrysler Aspen** hybrid; the **Mercedes M-Class** hybrid; and the **BMW X6** hybrid. GM also developed a mild hybrid system similar to the Honda hybrid drivetrain that was utilized in front-wheel drive sedans such as the **Saturn Vue** and **Chevrolet Malibu** hybrids.

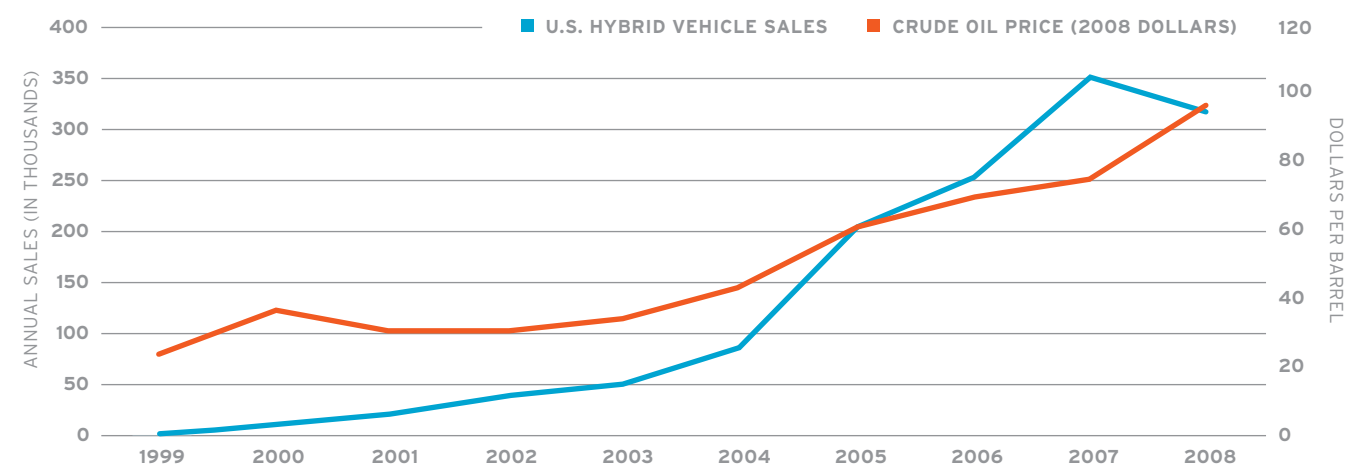
Ultimately, however, it is important to place the commercial success of HEVs in context. Even with the dynamic marketplace surrounding hybrids and the billions of dollars poured into the development of the systems, up-front costs for the vehicles and fluctuating oil prices have prevented large scale adoption. In the United States, hybrids have never surpassed 3 percent of new vehicle sales, and currently represent less than 1 percent of total light-duty vehicles on the road.

Moreover, from an energy security standpoint, HEVs are inherently limited. Because they still depend heavily on an IC engine for propulsion, HEVs have an upper bound on fuel savings, regardless of the driving patterns of consumers. Considered in this light, HEVs are simply a means of deploying technology to increase the efficiency of conventional vehicles. Nevertheless, traditional hybrids will continue to play an important role in meeting fuel-economy requirements as well as driving scale production of key components shared between HEVs and GEVs.

TECHNOLOGICAL STEP CHANGE: PLUGGING BATTERIES INTO THE GRID

Grid-enabled vehicles represent a step forward from HEVs. By drawing power from the electric grid via charging, GEVs are able to incorporate larger batteries that allow the electric drivetrain to power the vehicle over longer distances at all speeds without using gasoline. In other words, the GEV concept introduces the ability to fully substitute for petroleum in the transportation sector, in theory achieving 100 percent gasoline fuel efficiency with certain important exceptions.

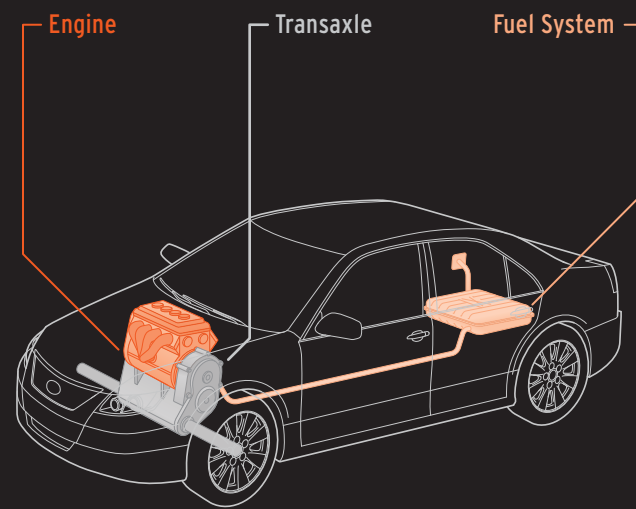
FIGURE 2A OIL PRICES AND HEV SALES, U.S., HISTORICAL



Source: DOE, EIA; SAFE Analysis

FIGURE 2B Vehicle Configurations

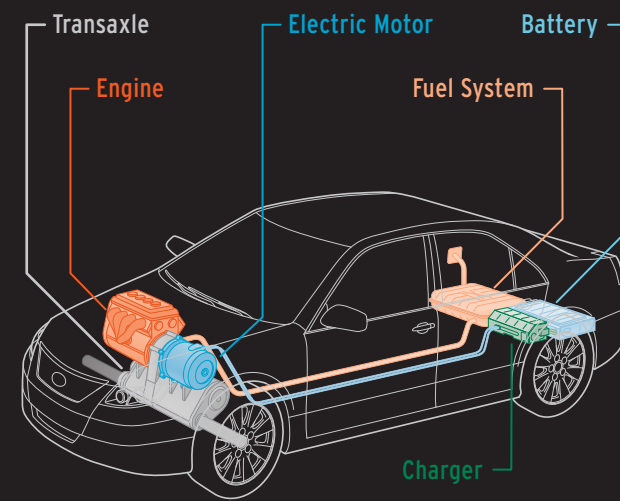
INTERNAL COMBUSTION ENGINE VEHICLE



KEY FEATURES

Traditional IC engine vehicles store liquid fuel—typically gasoline or diesel—onboard in a fuel tank. Fuel is combusted in the engine, which delivers mechanical energy to the axle to propel the vehicle. The high energy density of gasoline and the ability to store significant volumes of fuel onboard allow IC engine vehicles to travel several hundred miles without refueling. Today's internal combustion engines, however, are highly inefficient. IC engine automobiles turn less than 20 percent of the energy in gasoline into power that propels the vehicle. The rest of the energy is lost to engine and driveline inefficiencies and idling.

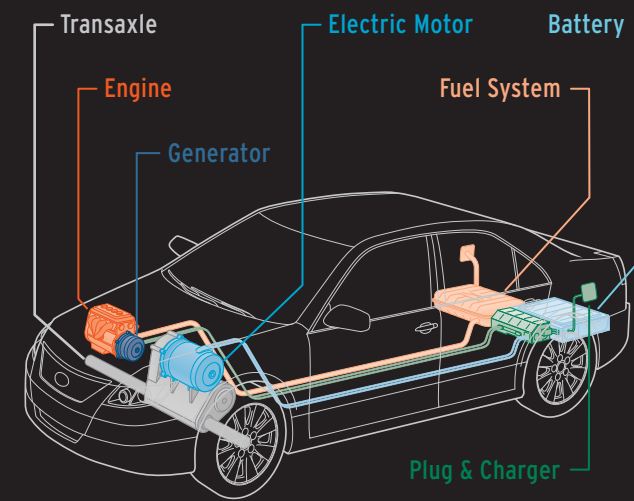
HYBRID-ELECTRIC VEHICLE (HEV)



KEY FEATURES

HEVs retain the use of an IC engine, and therefore require a liquid fuel tank. Additional energy is stored in a battery, from which electricity flows to an electric motor. The motor transforms electrical energy into mechanical energy, which provides some measure of torque to the wheels. In a typical parallel hybrid system, both the engine and the motor provide torque to the wheels. In a series hybrid system, only the electric motor provides torque to the wheels, and the battery is charged via an onboard generator. Power split systems utilize two electric motors and an IC engine. Both the engine and the larger electric motor can provide torque to the wheels—jointly or independently.

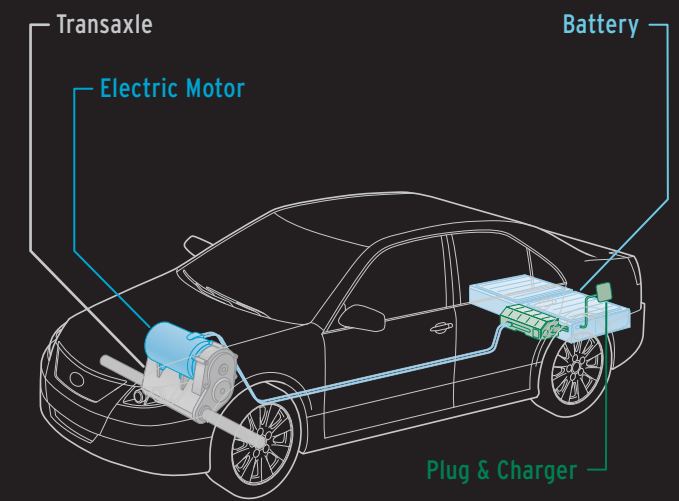
PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)



KEY FEATURES

Like traditional hybrids, PHEVs retain the use of an internal combustion engine and fuel tank while adding a battery and electric motor. However, PHEVs utilize much larger batteries, which can be charged and recharged by plugging into the electric grid. PHEV batteries are capable of powering the vehicle purely on electricity at a normal speeds over significant distances (approximately 40 miles) without any assistance from the IC engine. When the battery is depleted, PHEVs use the IC engine as a generator to power the electric motor and extend their range by several hundred miles. PHEVs can be configured as a series hybrid system or a power split system.

ELECTRIC VEHICLE (EV)



KEY FEATURES

EVs do not incorporate an IC engine or conventional fuel system. Electric vehicles rely on one or more electric motors that receive power from an onboard battery to provide the vehicle's propulsion and operation of its accessories. EV batteries, which are typically larger than batteries in HEVs or PHEVs to support vehicle range, are charged by plugging the car into a device (electric vehicle service equipment) that receives electrical power from the grid.

HYBRID ELECTRIC VEHICLE SYSTEMS

MILD HYBRID (PARALLEL SYSTEM)

- Still relies heavily on IC engine
- Efficiency gains of 15 to 20 percent
- Battery provides additional power during acceleration; powers the A/C and other systems during idling
- Regenerative braking charges battery

FULL HYBRID (POWER-SPLIT SYSTEM)

- Still relies on IC engine, but less than mild hybrid
- Efficiency gains of 25 to 40 percent
- Larger battery provides enough power for autonomous driving at low speeds
- Smaller motor acts as generator to charge the battery

PLUG-IN HYBRID ELECTRIC VEHICLE SYSTEMS

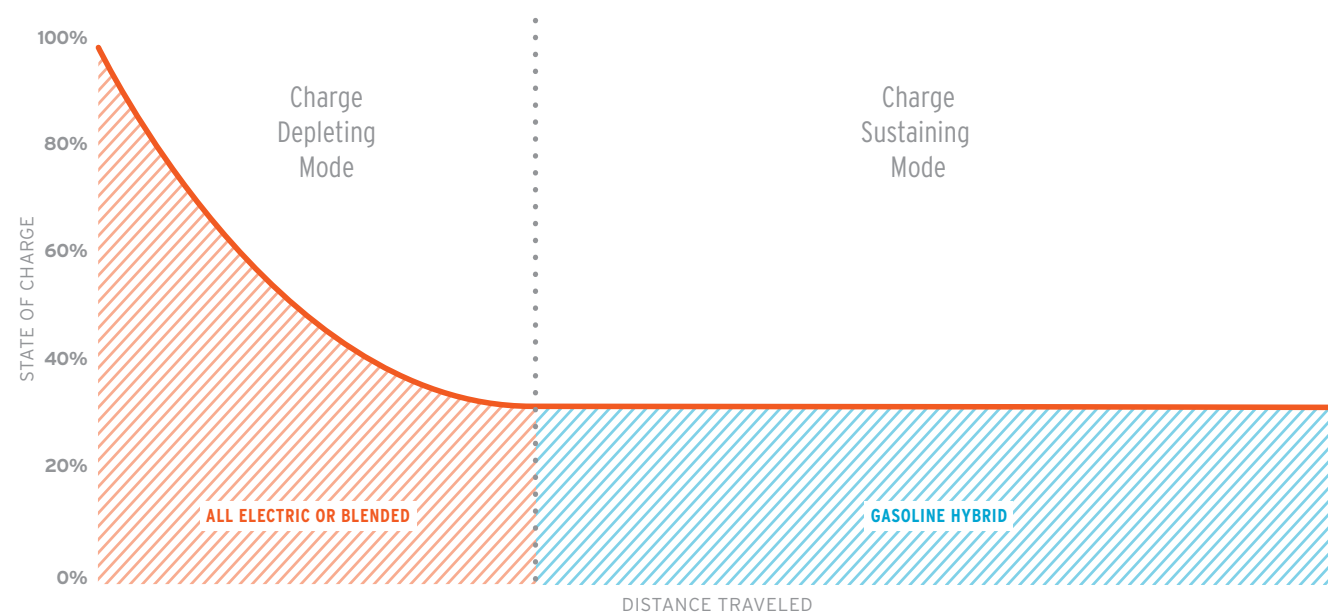
PHEV (SERIES HYBRID SYSTEM)

- Only electric motor provides torque to wheels
- IC engine serves only to augment the battery after depletion
- Uses no gasoline while battery is sufficiently charged
- Charges battery through grid connection and regenerative braking

PHEV (POWER-SPLIT SYSTEM)

- Both the motor and IC engine can provide torque to the wheels
- IC engine provides torque when required (blended mode)
- Charges battery through grid connection and regenerative braking

Today's familiar hybrid-electric vehicles offer improved efficiency over traditional internal combustion engine automobiles. However, by incorporating a larger battery and drawing electric power from the grid, plug-in hybrids and pure electric vehicles offer a step change improvement in vehicle efficiency.

FIGURE 2C CONCEPTUAL ILLUSTRATION OF BATTERY DISCHARGE


Source: SAFE Analysis

The earliest efforts to develop GEVs focused on pure electric vehicles (EVs). EVs do not contain an IC engine or gasoline fuel tank. In fact, pure EVs do not require a number of the components common to conventional vehicles, and therefore are in principle a far more simple technology.

Because EVs do not incorporate an IC engine, however, their range is limited to that which can be derived from the energy contained in the battery. Once the battery is depleted, pure EVs must recharge before further use. This limitation has historically been viewed as a substantial drawback for consumers, particularly in the United States. With an HEV or a traditional IC engine vehicle, consumers are confident that as their fuel level drops, there is ample refueling infrastructure in place to fill their tank when needed. Further, when they do need to refuel, they know it will only take a few minutes. An EV driver today would have essentially no public refueling infrastructure available. Moreover, even if they were to happen upon an opportunity to plug in, current infrastructure would require them to spend several hours charging before being able to continue their trip.

Because of these technological and structural obstacles, the current iteration of vehicle

electrification has seen the emergence of the plug-in hybrid electric vehicle, or PHEV. The PHEV increases the size of the standard HEV battery, adds a plug to charge the battery, and maintains the use of an IC engine. A PHEV can be configured in power split or series format. A series drivetrain powers the vehicle strictly using the electric motor, which derives power from the battery. The battery is charged either with power from the grid (through the plug) or with power from the IC engine via a generator. The power split configuration simply adds a direct connection between the engine and the wheels. This gives the IC engine the potential to power the vehicle in conjunction with the electric motor or independently.

Despite its retention of an IC engine, a PHEV is capable of pure electric driving at the full range of normal speeds over substantial distances. In a typical PHEV configuration, when the vehicle's battery is fully charged, it will operate in pure electric mode. During all electric operation, the vehicle operates in charge depleting mode, drawing down power exclusively from the battery. Either at a maximum speed (where the electric motor cannot alone maintain the vehicle's speed), or after the battery reaches a minimum state of charge, the internal combustion engine

will activate, propelling the vehicle in a traditional hybrid mode. This operation is typically referred to as charge sustaining mode.

A variation on this basic PHEV configuration would be to blend IC engine torque with battery power for certain functions during charge depletion. The vehicle would still rely heavily on the electric drivetrain for torque at speeds and acceleration rates higher than would be the case in a traditional HEV and would, therefore, still draw down the battery's state of charge. However, the blended use of an IC engine during charge depleting mode would allow for a smaller, less costly battery.

Though a number of OEMs have announced plans to introduce PHEVs in 2010, there are currently no plug-in hybrids commercially available in the United States. For several years, Ford has been carrying on demonstration projects with several utilities, most notably Southern California Edison, using a fleet of Escape plug-in hybrids.¹¹ Toyota has placed a small number of Prius plug-in hybrids with various fleets in 2009 and plans to increase that number annually as a precursor to volume production.¹² Several third parties have been offering conversion kits that will change a traditional hybrid into a plug-in hybrid. These conversions are typically available only for the Prius and carry a price tag of up to \$15,000, far more than an owner is ever likely to recoup in gasoline savings.¹³

BEYOND HYBRIDIZATION: PURE ELECTRIC MILES

Beyond HEVs and PHEVs are pure electric vehicles, or EVs. Over the long term, pure electric propulsion is likely the better technological platform, regardless of the target market. Pure EVs are simpler to produce and less cost-intensive than PHEVs, because they do not require the redundancy of both an IC engine and electric motor. They are powered solely

by an electric drivetrain featuring a battery and an electric motor. The only highway-capable, commercially available EV sold today in the United States is the Tesla Roadster. However, most major automotive manufacturers and countless small start-up automakers are promising a number of EV introductions over the next several years.

Ultimately, an EV that meets all consumer requirements—range, convenience, etc.—at cost parity to a comparable conventional vehicle would make the notion of PHEVs obsolete. Yet a number of important challenges stand in the way of making such vehicles practical for most consumers. The costs for a pure EV are likely to prevent widespread adoption at today's battery prices, particularly without more aggressive government support. Moreover, deploying adequate infrastructure to support pure EVs could be a daunting challenge without the appropriate public policies and regulatory framework.

¹¹ "Ford Motor Company and Southern California Edison Join Forces to Advance a New Transportation and Energy Vision," Edison International (July 9, 2007), available at www.edison.com/pressroom/pr.asp?id=6804, last accessed on October 23, 2009.

¹² Maynard, Micheline. "Toyota Will Offer a Plug-In Hybrid by 2010," *The New York Times*, (January 14, 2008), available at www.nytimes.com/2008/01/14/business/14plug.html, last accessed on October 23, 2009.

¹³ Kanellos, Michael. "The payoff for plug-in hybrids: 95 years?" *Green Tech*, (March 26, 2008), available at news.cnet.com/8301-11128_3-9903014-54.html, last accessed on October 23, 2009.

2.2.1 The Battery

The battery is a core component in a GEV. Lithium-ion batteries provide requisite energy and power, but add significantly to vehicle cost. Raw materials like lithium are abundant, especially if recycled. Improvements in battery performance are still needed.

No obstacle to GEV adoption has been as formidable as the development of battery technology. In short, batteries have never been able to compete with the tremendous energy density of petroleum fuels. Converted to a kilowatt hour (kWh) basis, 10 gallons of gasoline contain approximately 360 kWh of usable energy.¹⁴ However, the low efficiency of current generation IC engines means that only around 72 kWh of this energy is actually used.¹⁵ And yet, matching even half of that energy with a large-format automotive battery has historically been either impossible or so costly (more than \$1,000 per kWh) that it made little practical sense.

The last several years, however, have seen enormous strides in battery technology, substantially lowering cost and increasing range potential. This rapid progress has enabled the design and manufacture of grid-enabled vehicles that can compete with the performance and convenience of gasoline-powered cars. Improvements in battery performance can be grouped into at least five categories: power, energy, safety, life and cost. These categories were adopted by the United States Advanced Battery Consortium in 2007 as the key indicators for setting battery development goals and measuring progress. In general, it is challenging to achieve high levels of success across all categories, though that will ultimately be required for widespread consumer acceptance.

Power

Power is the rate of energy transfer, measured in kilowatts. For GEV batteries, power is the rate at which energy can be delivered from the battery to the wheels.

¹⁴ SAFE calculations assuming 122,786 Btu per gallon of gasoline and 3,412 Btu per kWh.

¹⁵ Assumes IC engine efficiency of 20 percent. For a review of IC engine efficiency, see: DOE, EERE, "Advanced Combustion and Emissions Control Technical Roadmap for Light-Duty Powertrains," at 8 (Table 1a) (2006).

All things being equal, higher power rates in a given vehicle equate to a greater share of acceleration propulsion for the electric drivetrain. In IC engine terms, 100 horsepower equals 75 kilowatts.

Energy

For GEV batteries, energy is used as a metric to measure storage capacity. Higher energy batteries allow the vehicle to remain in charge depleting mode for greater distances (all other things being equal). Energy capacity is measured in kilowatt hours (1 kWh is equivalent to 1 kilowatt provided for 1 hour).

Safety

Because large-format automotive batteries store energy and contain some volatile chemicals, safety is an important consideration. Most batteries rely on some form of chemical reaction in order to discharge electricity. Short circuits, overcharging, high heat exposure, and high impact collisions all have the capacity to damage batteries. Performance under these conditions varies by battery system design (cells, mechanical, electronics and control software) but commercialized batteries will need to perform safely under both typical and extreme driving conditions.

Life

With use over time, battery performance can substantially degrade across all performance metrics, including energy, power, and safety. Calendar life is simply the ability of the battery to withstand degradation over time, and is generally independent of use. More importantly, cycle life measures the number of times a GEV battery can be charged and discharged before energy and power capacity fall. Cycle life, in turn, varies by the type of cycle—deep or shallow.



Cost

The cost of GEV batteries will ultimately determine their level of adoption. Cost varies by manufacturer based on chemistry, technology, and other factors like labor and capital costs. The current industry-wide average is \$600 per kWh, with a number of individual companies achieving lower costs.

THE EVOLUTION OF BATTERY CHEMISTRIES

For decades, the traditional automotive battery has been based on lead acid chemistry. Although these batteries are significantly heavier than other battery chemistry types, certain characteristics made them very attractive in conventional internal combustion engine vehicles. Lead acid batteries, when compared with other secondary batteries, have the ability to provide very high currents for a short duration, which is an ideal feature for starting an IC engine (the primary responsibility of traditional automotive batteries). Additionally, lead acid batteries are relatively inexpensive, on the order of \$100 to \$200 per kWh. However, the drawbacks of the lead acid battery, notably its lack of energy density, its short duration of available power, and its weight, led automakers to look for better alternatives upon the advent of hybrid and electric vehicles.

The first chemistry that replaced lead acid in automotive applications was nickel metal hydride (NiMH). NiMH batteries are superior to lead acid batteries in almost every category except for cost. Though more expensive, they offer far better energy density and, therefore, are much lighter for a given amount of required energy. NiMH batteries were used on the previous generation of plug-in vehicles, including the GM EV1, the Toyota RAV4-EV, and the Ford Ranger EV, all sold in California under the original Zero Emissions Vehicle (ZEV) mandates.

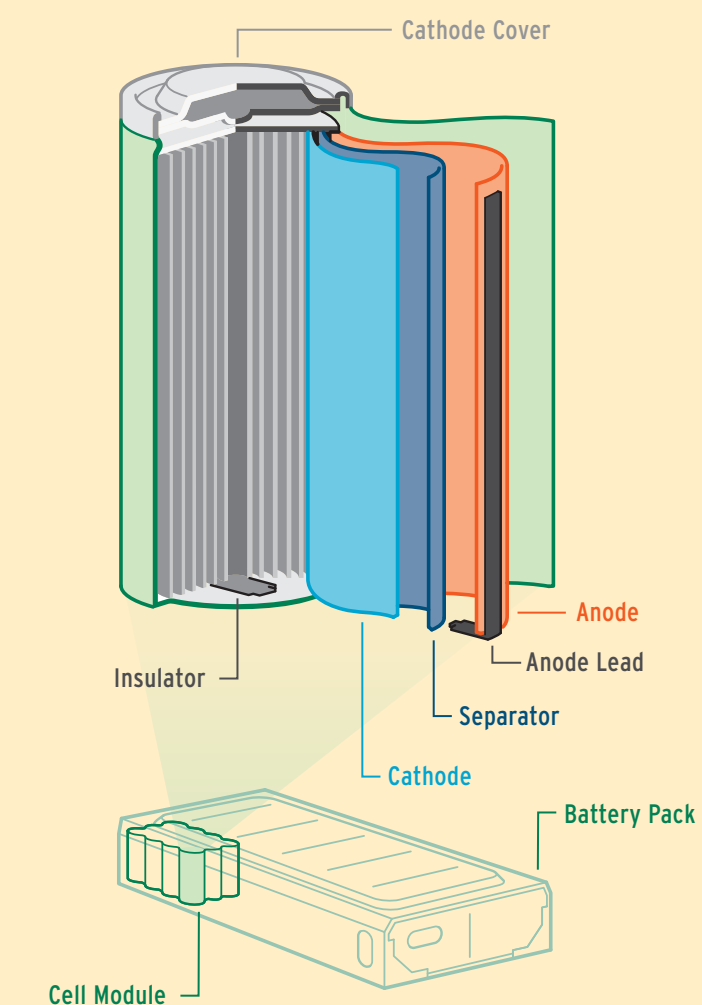
NiMH batteries continued to be used when HEVs were introduced and can be found in almost all hybrid vehicles currently in production, including the Toyota Prius, the Honda Insight, the Ford Escape Hybrid, the Ford Fusion Hybrid, and the Chevrolet Malibu Hybrid.

Although much of the focus recently has shifted to the development of lithium-ion batteries, some NiMH production capacity and use in HEVs is likely to persist over the short term. In September 2009, for example, Toyota announced that after extensive testing and

LITHIUM-ION BATTERIES

The most basic component in a lithium-ion battery is the cell. Cells can be designed differently depending on the type of vehicle and performance needs (power vs. energy). Generally, a low number of cells—perhaps 6 to 12—are assembled into a module, with each module containing its own control circuitry. Modules are then combined into larger battery packs.

CYLINDRICAL LI-ION CELL SECTION



Source: Argonne National Laboratory

development of lithium-ion batteries, it would continue to exclusively use NiMH batteries in its range of traditional hybrid vehicles.¹⁶

As plug-in hybrids begin to arrive on the market, most every incarnation will use lithium-ion based batteries. Lithium-ion batteries, constructed using the lightest metal in the periodic table, promise far better energy density and power density, enabling very large batteries with long ranges to be placed in vehicles while minimizing the weight and size burden that NiMH or lead acid batteries would necessitate. The vast majority of automotive battery research initiatives and vehicle production programs worldwide are focused on some type of lithium-ion battery chemistry. Lithium-ion, however, is an umbrella term that incorporates several competing battery chemistries, all vying for a niche in the electric vehicle market.

POWER AND ENERGY

Regardless of chemistry type, battery design generally requires a trade-off between the two fundamental characteristics that govern the battery’s performance: power density and energy density. In an electric vehicle, power density can be thought of as the characteristic that provides rapid acceleration, and energy density relates to the length of charge depleting operation. Simply put, power density answers ‘How quick?’ and energy density answers ‘How far?’

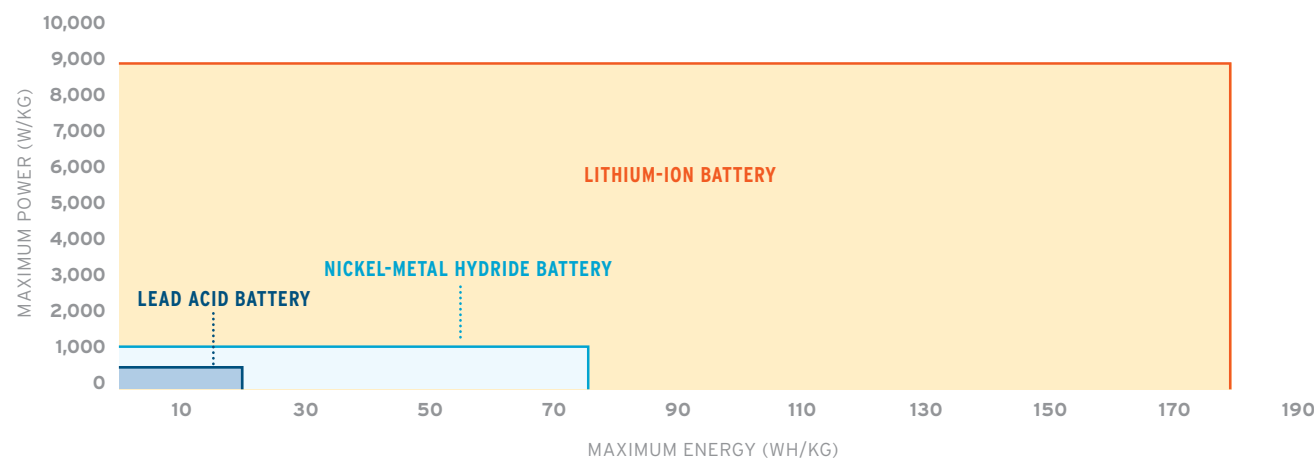
All battery chemistries have a theoretical boundary that ranges from higher power densities and lower energy densities to lower power densities and higher energy densities. Lead acid batteries have a maximum theoretical energy density of around 25 watt-hours per kilogram (Wh/kg) and power density of up to 200 or 300 watts per kilogram (W/kg). Nickel-metal-hydrate batteries, in comparison, can achieve maximum energy densities ranging from 50 to 75 Wh/kg with associated power densities of approximately 10 to 1,000 W/kg.

Lithium-ion batteries are attractive because they deliver superior performance in both power and energy density, allowing them to achieve a much higher weight to performance ratio than either of their predecessors. Lithium-ion battery chemistries can achieve theoretical energy densities from 50 to 175 Wh/kg and power densities of 10 to 9,000 W/kg. However, as research into energy storage and lithium-ion chemistries has steadily progressed, some laboratory results suggest that it may be possible to surpass even these boundaries. Stanford scientists published research in August 2009 claiming energy density of up to six times greater than the previously mentioned limits.¹⁷ Later, in September 2009, Toyota researchers in partnership with Tohoku University claimed energy storage of up to 10 times greater than current batteries.¹⁸

17 Patel, Prachi, “Nanowire Advance for Lithium Batteries,” MIT Technology Review, (August 14, 2009), Available at www.technologyreview.com/energy/23240/?a=f.

18 Greimel, Hans, “Toyota Improves Lithium-Ion Batteries,” Automotive News Europe, (August 20, 2009), Available at www.autonews.com/article/20090820/COPY/308209998/-1.

FIGURE 2D BATTERY PERFORMANCE PER TECHNOLOGY



Source: PRTM, SAFE Analysis



BATTERY LIFE FACTORS

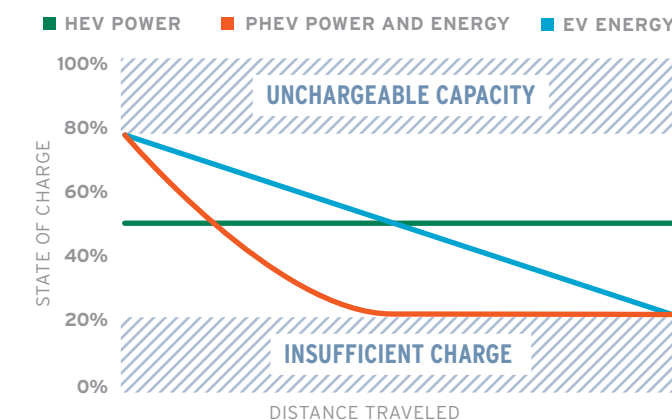
The expected life of automotive grade lithium-ion batteries is far from certain. Though lithium-ion battery technology has been available commercially since the early 1990s, battery longevity and performance when exposed to the extreme operating environment of an automobile is still in question. Used chiefly in consumer electronics, which are generally viewed as disposable, lithium-ion batteries have typically not been expected to last the 10 or more years that vehicles are expected to endure. So although there is plenty of laboratory testing that defends the durability of lithium-ion batteries when faced with these constraints, there is still no real market data that assures their adequate performance. The primary factors that contribute to the degradation of a battery’s performance are cycling and temperature, both of which are potentially present in a detrimental manner in cars.

Cycling

Cycling refers to the process of discharging and recharging batteries. The cycling of lithium-ion batteries is most detrimental to their health when they are deeply discharged; that is, when their energy is so completely depleted the remaining state of charge of the battery is very low. Alternatively, battery health is also severely damaged when the battery is held at a very high state of charge for long periods of time. At a practical level, the deleterious effects of deep cycling and overcharging result in a rapid reduction of usable battery capacity. In an electric vehicle, this would effectively shorten the range of the car and ultimately cut short the calendar life of the battery.

To mitigate this effect, automakers are integrating into their batteries a reserve portion at the low end of the state of charge and sometimes an additional reserve portion at the high end of the state of charge. The reserve portion at the low end prevents the battery from ever being fully discharged. The reserve portion at the high end prevents overcharging. For example, of the 16 kilowatt hours of energy capacity in the Chevrolet Volt, the actual used capacity will only be approximately 50 percent (8 kWh), because the battery only cycles from a maximum 80 percent state of charge down to a minimum 30 percent state of charge. This extra capacity is designed to achieve the vehicle’s target life of 10 years and 150,000 miles.

FIGURE 2E CONCEPTUAL ILLUSTRATION OF BATTERY DISCHARGE



This ‘over-specification’ of battery capacity is certainly not unique to one automaker. Pure EVs that are coming to market have typically achieved vehicle efficiencies ranging from three to five miles per kWh of energy density. Assuming an average range of four miles per kWh, a typical EV would need 25 kWh of usable battery capacity to drive 100 miles. Yet EVs specified at 100 miles of range have incorporated a 30 kWh battery, indicating the presence of a 20 percent reserve portion.

Over-specification will serve an important purpose in the early stages of GEV development. However, over-specifying battery energy density also adds significantly to total battery cost. Therefore, having a real-world understanding of how the battery will behave over time and over different cycle profiles will eventually be critical in order to minimize the amount of over-specification required to protect the battery’s health and therefore reduce GEV costs. Getting GEVs on the road in high quantities will be central to facilitating this learning process.

In addition, the widespread deployment of GEVs may require some fundamental changes in the vehicle ownership model. Battery financing models and network operator models (battery swapping) can help to de-risk the GEV proposition for consumers and dramatically lower upfront costs. But these business models also raise important questions about the ultimate responsibility for guaranteeing performance over the life of the battery. Current regulations in California and some other states that require manufacturers to warranty PHEV batteries for 10 years or 100,000 miles may hinder the earliest efforts to develop cost-

RISK MITIGATION AND COST VARIABILIZATION: WHO SHOULD OWN THE BATTERY?

With battery functionality (power and energy) having reached competitive levels, many GEV market participants have started to focus on creative ways to drive down costs for consumers while battery technology continues to advance.

A handful of companies have proposed various methodologies for battery financing. That is, instead of buying and owning the full vehicle, a consumer might buy only the vehicle, but finance the battery over time. A traditional leasing model, in which a third party owns the battery and consumers pay monthly rates, is one such option.

An alternative methodology might be for manufacturers to offer consumers a battery buy-back guarantee. In essence, this approach would allow consumers to own vehicles and all their components, but mitigate upfront costs by giving consumers the ability to recoup capital outlay after a defined period.

On some level, both the battery leasing model and a battery buy-back model implicitly assume that the battery will have a second useful life after its use in a grid-enabled vehicle. Options for secondary battery use (such as residential backup power, storage for intermittent renewable electricity supplies, or in secondary vehicle markets) have generated a great deal of interest, but without further testing, it is not clear what the performance of depleted batteries will be. As a result, the residual value of batteries is far from clear.

effective batteries by forcing manufacturers to over-specify battery capacity.

Temperature

Batteries need to be kept cool while in use, not completely unlike the current function of a cooling circuit in internal combustion engines. Although this is a relatively straightforward design issue, a great deal of current research is dedicated to developing cost-effective, efficient technologies for cooling batteries during operation.

Unlike conventional engines, however, lithium-ion batteries are also impacted by ambient temperature conditions when they are sitting idle, which is what most vehicles do more than 90 percent of the time. Consistent exposure to high ambient temperatures can have a negative impact on battery performance and life. According to one recent analysis, raising the average ambient air temperature experienced by a lithium-ion battery over its lifespan from 20°C to 30°C could cut in half the amount of time it takes for the battery to lose 30 percent of its power density.¹⁹ However, until there is sufficient data from large numbers of real vehicles in the field, no one knows exactly how batteries will perform across all consumer use cases.

BATTERY COST

Because battery cost will be central to GEV competitiveness, a number of current automotive battery initiatives are focused on driving down those costs. The United States Advanced Battery Consortium (USABC) has established multiple cost targets for automotive grade lithium-ion batteries. (USABC is funded by both the United States Council for Automotive Research and the Department of Energy.) The goals they have established are intended to enable plug-in vehicles that are competitive with IC engines in cost and performance.

For PHEVs with a 40-mile charge depleting range and a 17 kWh battery, USABC has set a target cost of \$200 per kWh.²⁰ For EVs with a 40 kWh battery, the consortium has set a near-term goal of \$150 per kWh and a long-term goal of \$100 per kWh. At these price

¹⁹ Ahmad A. Pesaran, National Renewable Energy Laboratory, "Battery Pack Thermal Issues and Solutions for PHEVs," presentation given at Plug-in 2009, Long Beach, CA.

²⁰ Healey, James R., "Test Drive: 2010 Ford Fusion is best gas-electric hybrid yet," USA Today, August 21, 2009.



points, the PHEV battery would cost roughly \$3,400, and the EV battery would cost between \$4,000 and \$6,000. When factoring in the lower cost of fuel and other operating expenses over the life of the vehicle, batteries in this price range would offer a substantially better value proposition to consumers than equivalent IC engine vehicles. (USABC has also developed a list of performance and life targets that ensure the batteries will last 15 years and perform as well as conventional IC engine vehicles while minimizing weight.)

Although these price targets are important, they are clearly aggressive, and there are still substantial obstacles to achieving them. In research published in May 2009, USABC detailed a number of existing batteries that meet their cycle life, specific power discharge, and power density goals. But these batteries are still far from meeting specification in temperature operating range, energy density, and, arguably most importantly, production price.

A range of current industry-wide estimates place the current (2009) production cost for lithium-ion batteries at roughly \$600 per kWh.²¹ Admittedly, this is a broad generalization that ignores production volume, chemistry type, vehicle type, and pack size. A number of companies have indicated that they have achieved lower cost structures, but the preponderance of estimates indicate that \$600 per kWh is a good approximation for the industry average. As grid-enabled vehicles begin to enter the marketplace in 2012, these costs are expected to have already begun to fall. Estimates place battery costs for that time period at around \$500 per kWh.

To understand the industry-wide focus on battery costs, consider that the current estimate of \$600 per kWh puts the cost of an average 30 kWh EV battery in 2009 at \$18,000. Since an electric drivetrain and a traditional internal combustion powertrain are roughly equivalent in price, an EV at this battery price will add almost the full \$18,000 to the price of a vehicle. Even with the drastic difference in price between gasoline and electricity, an EV driver would not be able to recoup this price difference over the life of the vehicle. Current government incentives (an EV with a 30 kWh battery would qualify for the full tax credit of \$7,500) would accelerate the payback period to eight

²¹ Kamath, Haresh, "Lithium Ion Batteries for Electric Transportation: Costs and Markets," Electric Power Research Institute, California Air Resources Board Presentation, September 22, 2009.

years, still longer than most consumers will be willing to wait. Beyond 2012, falling battery costs and government incentives could make a pure electric vehicle more economically sound, but the payback period would still be seven years.²²

With battery prices at \$600 per kWh, a PHEV offers a better value proposition to the consumer than either an EV or a conventional IC engine vehicle, but only when government subsidies are available. A 16 kWh battery will cost \$9,600, but will qualify for the full ARRA tax credit. Therefore, based on the existing tax incentives, the incremental, additional upfront vehicle costs for a 16 kWh PHEV are about \$2,100. Based on the lower cost of fuel over the lifetime of the vehicle, it is already economically rational for consumers to purchase a PHEV.

WHAT ARE THE DRIVERS OF BATTERY COST?

Raw materials

Lithium-ion batteries consist of an anode (negative electrode), usually graphite, and a cathode (positive electrode), which is some compound of lithium, most often a derivative of lithium carbonate (Li_2CO_3) or lithium hydroxide (LiOH). A variety of chemistries exist, however, each with its own advantages and disadvantages in terms of power, energy, and safety. Nickel and cobalt are most often used with lithium to form cathodes. Cathodes are the largest single contributor to battery cost, and together with the anode and electrolyte, account for more than 40 percent of the final price of the battery pack.²³ Naturally, these cost ratios are dependent on chemistry, cell type, and manufacturing, but they are broadly true using 2009 manufacturing processes and commodity prices.

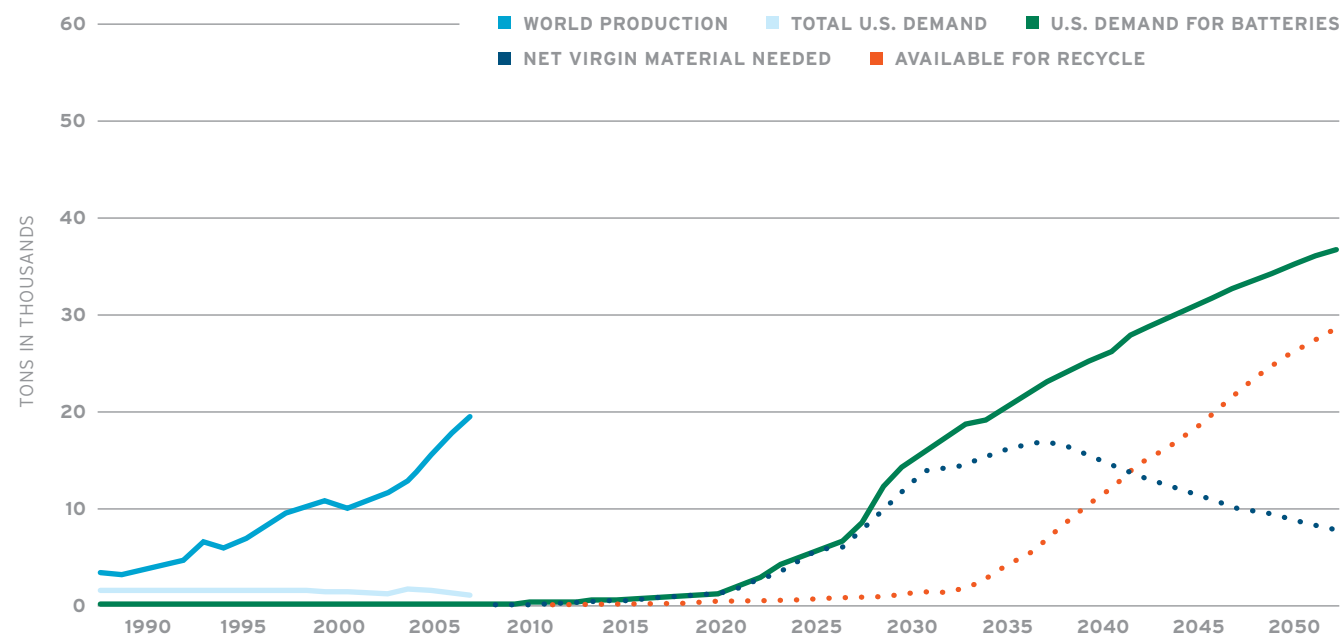
Most experts agree that the world does not face an imminent lithium shortage, regardless of the rate of electric vehicle penetration. Concerns about lithium dependence tend to ignore a key feature of lithium—its recyclability. Still, raw materials are a key driver of battery cost, and the largest known reserves are in just a few countries. Ensuring sufficient and affordable supplies of battery materials will be critical to the viability of GEVs.

Currently, only about 20 percent of lithium demand is for batteries. Other sources of demand

²² Id.

²³ Nelson, Paul, "Modeling Manufacturing Costs of Lithium-Ion Batteries for PHEVs," Argonne National Laboratory, Presented at Plug-In Conference, August 2009.

FIGURE 2F HISTORICAL AND PROJECTED CONTAINED LITHIUM DEMAND



Source: Center for Transportation Research, Argonne National Laboratory

include ceramics, glass, and lubricating greases.²⁴ Battery demand is expected to grow rapidly, however, and is exclusively driving an annual 7 percent increase in overall lithium demand each year. This growth has historically been mostly due to laptops and cell phones.²⁵ It is useful to note that an electric vehicle requires as much as a hundred times more lithium than a laptop.²⁶ Deployment of electric vehicles at the large scale proposed in this report will necessarily entail massive increases in lithium demand, at least initially. As demand increases, both supply and recycling capacity will increase as well. Investing early in recycling capacity will offset the need for ‘virgin’ lithium production and prevent dependence on imports from just a few countries. Today, because lithium demand and

prices remain low, almost none of the lithium used in consumer electronics is recycled.²⁷

It is important to avoid exchanging a dangerous dependence on a finite and foreign resource for another, and skeptics have raised the concern that relying on lithium-ion batteries would be doing precisely that. Modeling work at Argonne National Laboratory, however, concluded that there are plentiful lithium supplies, especially if recycling is considered. The Argonne analysis estimates bullish U.S. and global growth curves for electric vehicle penetration with four possible lithium-ion battery chemistries. The researchers found that in 2030, vehicles would require about 28,000 tons of net incremental lithium production, approximately equal to total production today. The need for new material rises until around 2035, at which point it begins to fall as sufficient recycled supplies account for a large fraction of new demand.²⁸

The amount of lithium required, of course, will depend on the extent of market penetration and the size of the typical battery. The Argonne National

²⁴ United States Geological Survey, Minerals Yearbook 2007, “Lithium,” available at minerals.usgs.gov/minerals/pubs/commodity/lithium/index.html#myb, last accessed October 1, 2009.

²⁵ United States Geological Survey, Minerals Yearbook 2007, “Lithium,” available at minerals.usgs.gov/minerals/pubs/commodity/lithium/index.html#myb, last accessed October 1, 2009; and “Strong Growth in Lithium Demand to Power FMC Corp., Rockwood Holdings,” Seeking Alpha, May 12, 2008, available at seekingalpha.com/article/76875-strong-growth-in-lithium-demand-to-power-fmc-corp-rockwood-holdings.

²⁶ Koerner, Brendan I., “The Saudi Arabia of Lithium,” *Forbes Magazine*, November 24, 2008.

²⁷ United States Geological Survey, Minerals Yearbook 2007, “Lithium,” available at minerals.usgs.gov/minerals/pubs/commodity/lithium/index.html#myb, last accessed October 1, 2009.

²⁸ Gaines, Linda, “Lithium-ion Batteries: Material Demand and Recycling,” Center for Transportation Research, Argonne National Laboratory, Presented at the Plug-In 2009 Conference, August 2009.

WHERE DOES LITHIUM COME FROM?



One of the abundant brine pools at Chaxa Lagoon on the Atacama Salt Flats in Northern Chile.

Lithium appears naturally in either mineral (spodumene) or salt form (brine pools) and can also be found embedded in hard clays. To date, only mineralized lithium and underground brines have been extensively explored and developed. Additionally, most calculations of reserves focus solely on underground brines, because they are relatively inexpensive and easy to mine. Both Australia and the United States have extensive reserves of mineral lithium, and between 1950 and 1985 the two nations dominated international lithium production. Over that time period, market prices hovered between \$4,500 and \$5,800 per ton (in 1998 dollars).

In 1985, Chemetall Foote, an American company, deployed technology to extract lithium from brine resources in the Salar de Atacama in Chile. Brine pools beneath the Chilean salt flats were found to contain high densities of lithium chloride. Using solar evaporation, lithium chloride is separated from the brines and converted to lithium carbonate, the building block for lithium-ion batteries. In 2000, as a result of expansion of lithium carbonate production from Chilean brines (and the development of Argentine brine resources), lithium prices fell to around \$2,000 per ton, where they remained for the first half of the decade. U.S. mines in North Carolina were closed, and Australia’s production became restricted to use in ceramic and glass production. Chilean production expanded rapidly. Today, the Salar de Atacama in Chile holds at least 20 percent of the world’s known reserves and supplies nearly 50 percent of global lithium demand.

Lithium brine resources are also present in Bolivia and the Qaidam basin in western China. The world’s largest deposit is in Bolivia, where the Uyuni desert holds more than 30 percent of known reserves. However, Bolivia has yet to produce commercial quantities of lithium. Its brine reserves are not as economical as those in Chile or Argentina due to salt ratios, altitude, weather and lack of infrastructure. In addition, President Evo Morales, having nationalized the country’s oil and gas industries, has been unwilling to surrender its lithium reserves to foreign operation.

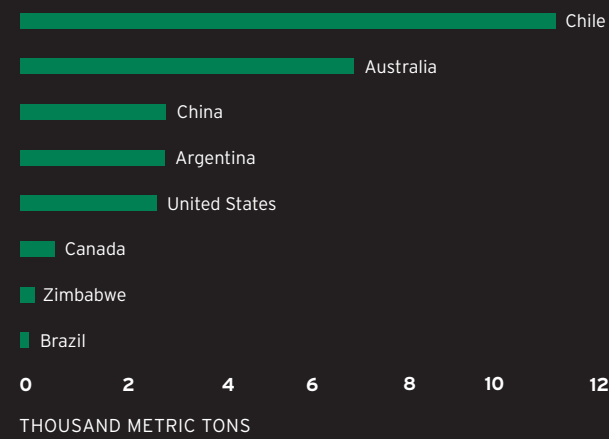
The U.S. Geological Survey identifies substantial lithium deposits in places as diverse as Austria, Afghanistan, India, Spain, Sweden, Ireland, and Zaire, but has not yet classified these deposits. Reserves also do not include the large quantities of lithium known to exist in oilfield brines in the western United States and in hectorite clays. Indeed, even the sea holds large quantities of dissolved lithium.

FIGURE 2G

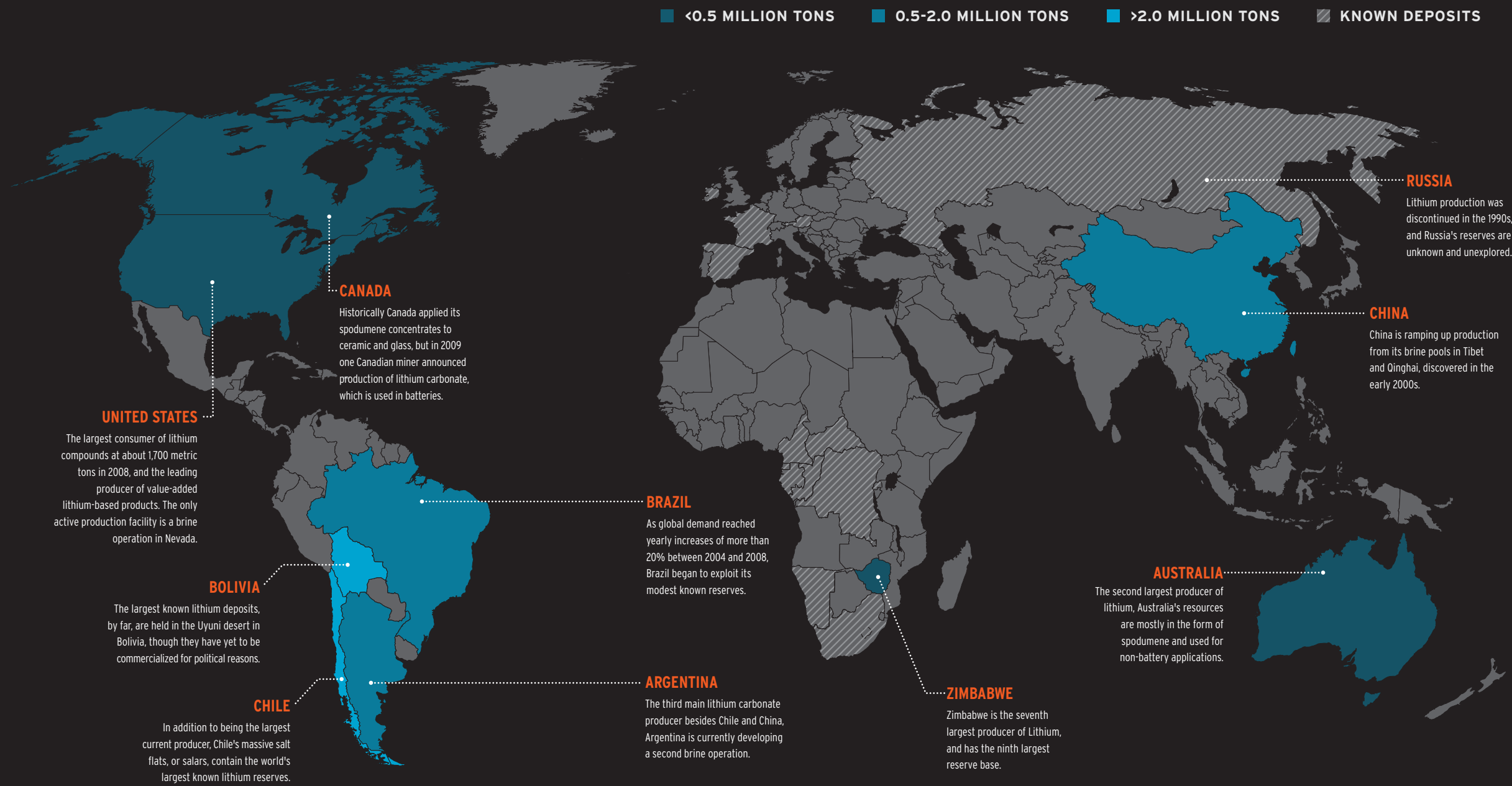
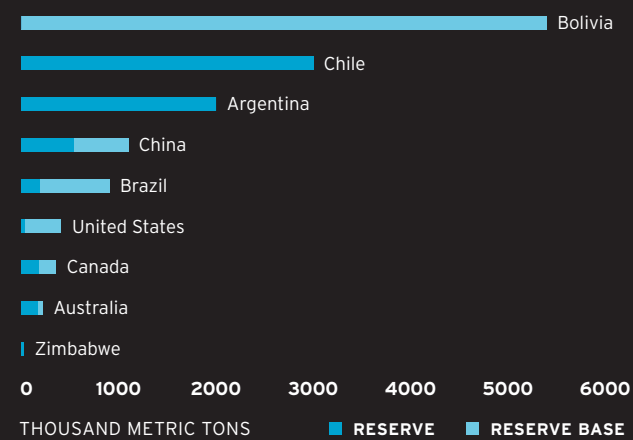
Lithium: Global State of Play

Total identified world lithium resources stand at around 13.4 million tons, according to USGS. Reserve estimates must be understood in the context of demand, which has thus far required only the cheapest and most accessible lithium to be developed. Further, unlike oil, lithium is recyclable. Though not currently economical, once the vehicle fleet is electrified it may be economical to reuse 100% of the lithium and other metals in batteries.

MAJOR LITHIUM PRODUCERS

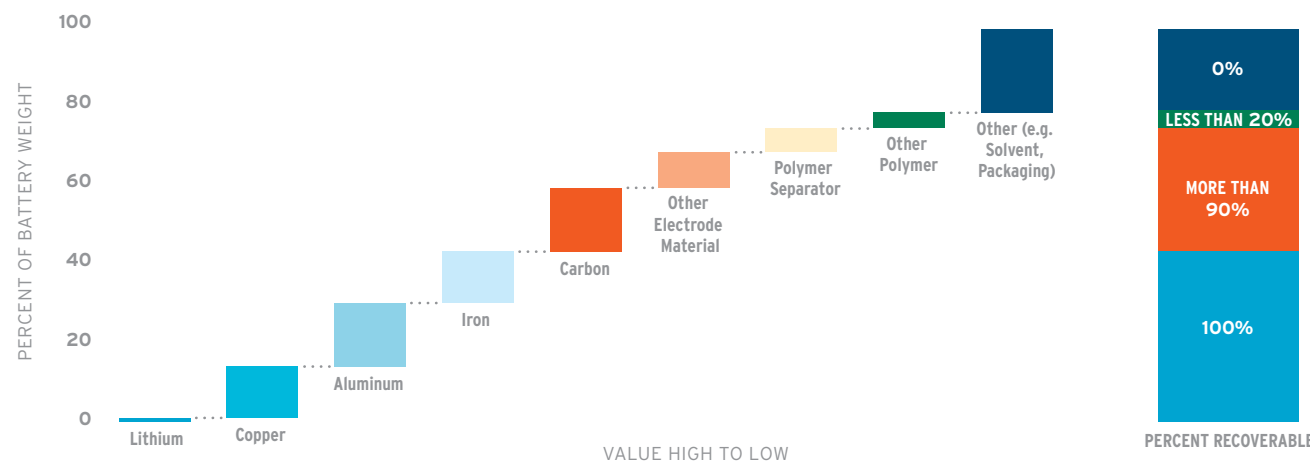


MAJOR LITHIUM RESERVE HOLDERS



Source: USGS

FIGURE 2H MOST OF A LITHIUM-ION BATTERY IS RECYCLABLE, BY VALUE AND WEIGHT



Source: A123 Systems

Laboratory researchers point out, however, that high demand and increased production will create a larger supply of recoverable material and that many other predictions have excluded recycled lithium.²⁹

Indeed, one of the principal characteristics distinguishing lithium from petroleum is its recyclability. Once an oil or natural gas molecule is combusted in a vehicle's engine, its energy potential is gone forever—hence the term, “non-renewable resource.” Lithium is not a non-renewable resource. Instead, it is a storage device. Once a vehicle battery has exceeded its useful life, it can be used for another application, like stationary power storage, that does not have the performance requirements of automotive grade batteries. Then, when a battery finally is discarded, smelters can liquefy the metals, and lithium can subsequently be extracted and reused. Toxco, an Ohio-based company, currently recycles lead-acid and nickel-metal hydride batteries. In August 2009, the Department of Energy awarded Toxco a \$9.5 million grant to expand its facility to recycle lithium-ion batteries as well.³⁰

This reveals a fundamental reason that lithium dependence is unlike oil dependence: we do not deplete batteries as we drive, we deplete the energy stored within them. Batteries are like the engines in conventional vehicles; though their life span is finite, they last for many years. As discussed in Part One of this report,

dependence on oil leaves us vulnerable because even a short-term supply disruption will bring our transportation system to an immediate halt. Alternatively, any future disruptions to lithium supplies, however unlikely, would not disrupt or disable the mobility of the electric vehicles already on the road. This gives the U.S. economy an important layer of insulation from global commodity markets.

Technology

Although there are many different types of lithium-ion chemistries in the research stage, only a select few are available or being readily commercialized. The first OEM lithium-ion battery to reach the market debuted in 2009 on the Mercedes Benz S400 BlueHybrid. This battery was integrated by **Continental** and developed by a partnership between **Johnson Controls** and **Saft**. The Johnson Controls-Saft partnership is pursuing a lithium nickel, cobalt, and aluminum (NCA) chemistry that has high energy density and life potential, and is cost-competitive at the battery pack level.

For the Volt, GM has sourced LG Chem for battery cells and will assemble the battery packs at their Brownstown, MI facility. This manganese-spinel based battery has similar cost and cycle life to the Johnson Controls-Saft battery, but has a lower energy density potential. This is an attractive chemistry, though, due to its stability and level of commercialization, and is being pursued by other notable battery producers including **AESC**, **Bosch-Samsung**, **Hitachi**, and **NEC**.

A third chemistry that is considered ready for production is lithium-iron phosphate. Compared to

29 Gaines, Linda, “Lithium-ion Batteries: Material Demand and Recycling,” Center for Transportation Research, Argonne National Laboratory, Presented at the Plug-In 2009 Conference, August 2009.
 30 Kamath, Haresh, “Lithium Ion Batteries: An EPRI Perspective,” EPRI, Presentation at Plug-In 2009 Conference.

OTHER METALS

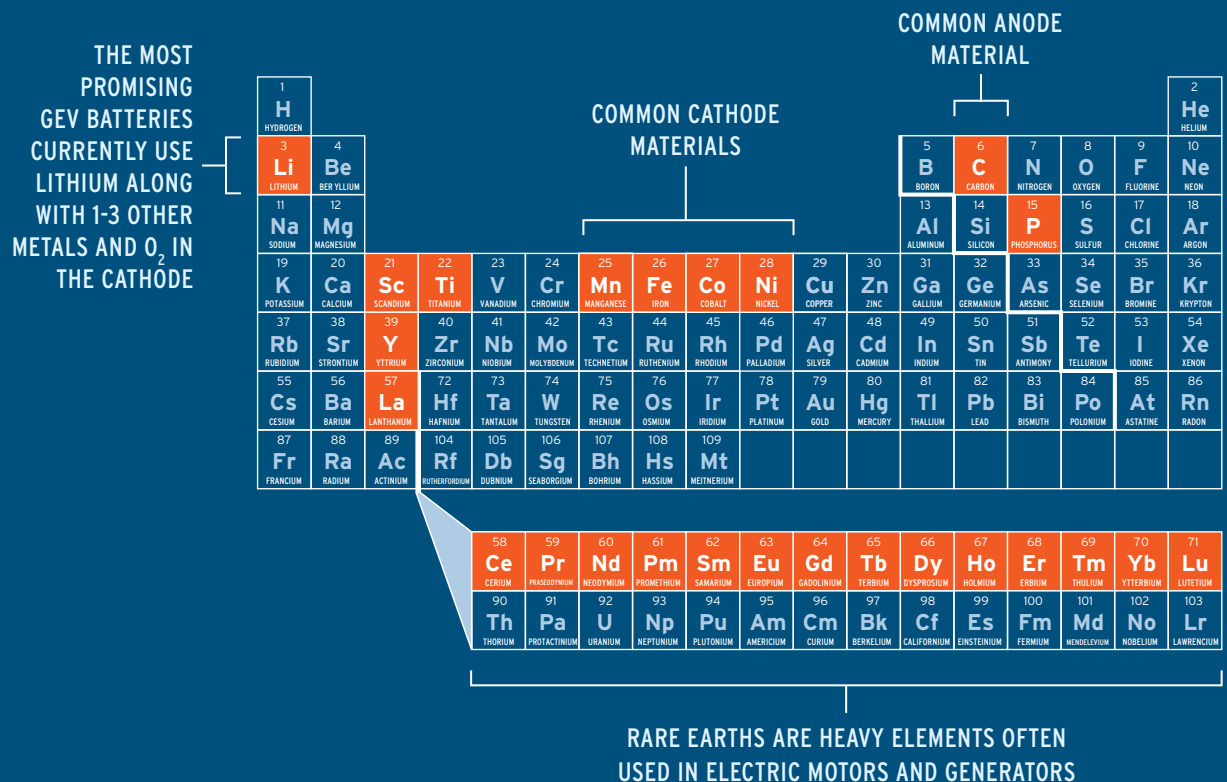
A variety of other metals are used in electric vehicles, including cobalt, graphite, nickel, manganese, phosphate, copper, and hard carbon. Nickel has long been used in a variety of sectors, especially for stainless steel production. Nickel-metal hydride is currently the chemical of choice for hybrid-electric vehicle batteries. Nickel is used in some lithium-based cathodes as well. Though its price has fluctuated over the years, there is little concern about nickel resource depletion. Extensive reserves are spread throughout the world: Australia, Canada and Russia hold dominant shares.

Cobalt is used along with lithium in some cathode chemistries. The vast majority of the world's cobalt reserves are held in Zambia, the Democratic Republic of Congo, and China. Cobalt's price tends to vary along with that of copper, with which it is usually mined in association. Though cobalt has been identified as a potentially scarce automotive component, such concerns are largely unfounded. With reserves of around 7.1 million tons, a reserve base of 13 million tons, and substantially more identified deposits, at production levels of 71,800 tons per year we are unlikely to “run out” anytime soon. Additionally, as with lithium and nickel, cobalt is recyclable.

A number of rare earth metals are also vital to GEV production. Among this class of metals, which are not scarce but rarely found in large deposits, neodymium, terbium, praseodymium, and dysprosium are used in electric motors and generators. Cerium and lanthanum are used in a variety

of automotive applications, including catalytic converters, diesel fuel additives, and nickel-metal hydride batteries. China holds around 30 percent of known rare earth reserves and produces over 95 percent of rare earth oxides. Beijing has recently enacted stringent export tariffs and quotas on unprocessed materials in an effort to ensure that all value-added processing, especially hard magnet production for batteries, occurs domestically. Global demand for rare earths is expected to grow rapidly—by around 15 percent annually for magnets and 20 percent for alloys—causing worry of a shortage and potential Chinese monopolistic manipulation. The United States also holds substantial reserves, but has opted to import Chinese supplies since the 1990s due to cost. One company, Molycorp, plans to reopen a significant U.S. mine at Mountain Pass, California.

Rare earth elements are recyclable, though at substantially greater cost than lithium or cobalt, because the amounts of rare earth used in any given product are often inconsequential. Some companies are investigating recycling opportunities, such as recovering waste during magnet grinding and polishing at the automotive OEM level. Without action to ensure a sufficient global supply of rare earth metals, supplies could tighten by 2012, particularly if wind turbine demand increases dramatically. Over the longer term, however, exploitation of known deposits, discovery of new sources (e.g. Russia, Africa), and improved recycling capability will likely suffice to meet demand regardless of the degree of GEV penetration.



RARE EARTHS ARE HEAVY ELEMENTS OFTEN USED IN ELECTRIC MOTORS AND GENERATORS

other lithium-ion battery chemistries, this chemistry is known to have average power and energy density, long life, and good thermal stability. The chemistry choice itself is typically more expensive, but the thermal stability reduces the need for control circuitry, making full battery packs price competitive. This is the chemistry being pursued by Massachusetts-based **A123 Systems** as well as China-based **BYD**.

The other major domestic automotive lithium-ion battery producer, Indiana-based **EnerDel**, is pursuing lithium titanate. Generally, this chemistry is considered to have lower power and energy density potential than its rivals with similar costs.

Beyond these leading chemistry types, significant research is being conducted on the next generation of chemistries, promising better performance, life, and cost. For example, manganese titanate offers superior power and energy density, though its life characteristics are uncertain.

Another primary driver of battery cost is the size of the battery pack. Naturally, the total cost for a large EV battery pack will be significantly more than a smaller PHEV pack. However, as the packs get larger, the per kWh price falls, and therefore an EV battery pack is actually cheaper on a per kWh basis.

Lack of scale

A main contributor to battery cost is lack of production volume, or scale. A plant that is capacitized to produce 10,000 battery packs per year as opposed to 100,000 will have battery costs that are approximately 60 percent to 80 percent higher.³¹

Manufacturing scale offers one of the largest opportunities for reduction in battery costs. This would be especially true if batteries were standardized. In August 2009, Ford executives called for standardization of battery types for this very reason.³² Achieving large numbers of production of common battery types has the potential to drive costs down faster than many of the research initiatives currently underway. Previously, in June 2009, GM global battery systems engineering manager Joe LoGrasso made a similar

appeal, suggesting that a convergence of cell formats may be a prerequisite to commercial success.³³

In a May 2009 Department of Energy review, research was presented that indicated using current materials and current processing technology, scaling up to 500,000 units per year would drive the cost of PHEV packs down to \$363 per kWh, nearly achieving the goals outlined by the USABC.³⁴ Additionally, the research indicated other possible manufacturing developments that could push that price down to meeting the USABC targets. This research indicates that lack of domestic scale is one of the largest contributors to the dearth of affordable plug-in vehicle batteries.

As of 2009, there is little installed manufacturing capacity for lithium-ion batteries, and the overwhelming majority of production activity is currently centered in Asia. In the coming years, however, U.S. production capacity is expected to rapidly increase as government loans spur accelerated investment from firms such as EnerDel, A123, Compact Power, and Nissan.

COST COMPETITIVENESS OF LOCALIZING CELL/COMPONENT PRODUCTION

Due to the high weight-to-volume ratio of completed batteries, they are typically unattractive candidates for shipping long distances. This explains in part the fact that the vast majority of worldwide battery production capacity has grown up directly next to the largest consumers of batteries: the consumer electronics manufacturing industry in Asia.

Nissan, with the help of DOE loans, has decided to assemble the battery packs for their upcoming EV production in Smyrna, TN at an adjacent battery production facility. Similarly, GM will be assembling the battery packs for the Chevrolet Volt at a plant in Brownstown Township, MI, not far from the Volt's Poletown assembly plant in Hamtramck, MI. Therefore, there are good economic arguments for the development of a strong domestic battery industry as an enabler for minimizing the cost and increasing the competitiveness of domestically produced electric vehicles.

31 Nelson, Paul, "Modeling Manufacturing Costs of Lithium-Ion Batteries for PHEVs," Argonne National Laboratory, 2009, Presented at Plug-In 2009 Conference.

32 "Ford's View on Electrification Enablers; Looking for Battery Commonization," Green Car Congress, (August 15, 2009), Available at www.greencarcongress.com/2009/08/tinskey-20090815.html#more.

33 "GM Urges Convergence on Li-ion Battery Formats," Green Car Congress, (June 9, 2009), Available at www.greencarcongress.com/2009/06/lograsso-20090609.html#more.

34 Barnett, Brian, et. al., "PHEV Battery Cost Assessment," Tiax LLC, (May 19, 2009), Presented at the May 2009 DoE Merit Review.



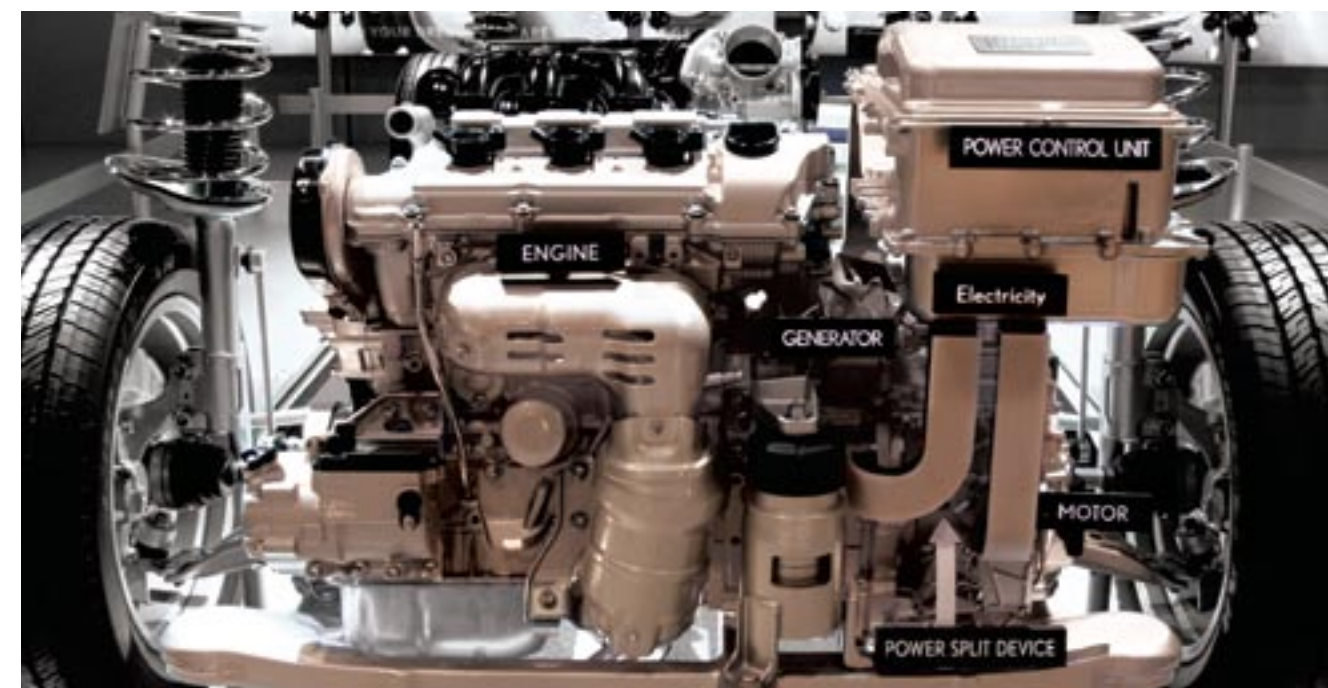
2.2.2 Electric Motors

The efficiency of the electric motor as compared to an IC engine is the primary reason that GEVs are more efficient than traditional vehicles. Advances in electric motors will continue to improve the cost effectiveness of GEVs.

The high efficiency level of grid-enabled vehicles is largely due to the capabilities of electric motors. Whereas traditional internal combustion engines have efficiency ratings between 20 and 30 percent, electric motors can already turn as much as 90 percent of the energy in electricity into mechanical energy. This high level of efficiency is the driving force behind the reduced energy consumption and lower emissions of GEVs.

The motors and power electronics needed for production of all electric vehicle types are not as critical to achieving cost parity for consumers as are the batteries. However, the investment into research and development of these components is no less critical to the success of GEVs. As these vehicles begin to come to market in large numbers and production capacity increases, there are opportunities for cost reductions due to scale and design efficiency improvements.

One component of the Department of Energy's Office of Energy Efficiency and Renewable Energy's (EERE) Vehicle Technologies Program is research into the development of power electronics and electric motors. Just as the USABC has laid out goals for the development of lithium-ion batteries, the Vehicle Technologies Program is pursuing goals for the commercialization of the electric drivetrain. To achieve their cost and performance goals, the cost of components must be reduced by 80 percent and the power increased by 50 percent. Electric motors are already significantly more efficient than internal combustion engines, and the program's goals therefore only identify a 10 percent improvement target in efficiency. To make the systems lighter, they have established a goal to increase power density by 55 percent.



The Lexus Hybrid Engine is displayed at the 36th Annual South Florida International Auto Show at the Miami Beach Convention Center on October 10, 2006 in Miami Beach, Florida. (Photo by Victor Malafrente/Getty Images)

2.2.3 OEM Production Format/Supply Chains

Today, only a handful of grid-enabled vehicle models exist globally. While a number of automakers have announced plans to produce GEVs, the ability of manufacturers to scale up production quickly will be a key challenge to electrification.

In order to produce high numbers of plug-in vehicles, many traditional components will have to be redesigned. The suppliers of these parts will be required to invest in new production capacity, something that is a difficult proposition for the strained domestic automotive parts industry.

Many of the subsystems in traditional internal combustion powertrains are belt driven. That is, the power to run the subsystem is derived from a belt that is connected to the engine. Typical belt-driven components are water pumps and power steering pumps. However, electric vehicles do not accommodate belt driven components, so the vehicle subsystems must be electric.

Although a conversion from belt-driven to electrically-driven vehicle systems is relatively straightforward, the historical preponderance of the belt drive has negated any incentive for vehicle suppliers to invest in this new type of technology. As Toyota's Hybrid Synergy Drive has iterated through several generations, the number of electrically-driven components has slowly increased. Similarly, as the Chevrolet Volt has been developed and the published costs of the vehicle have risen past

expectations, some have speculated that the replacement of belt-driven components with electrically-driven components has been a prime driver of cost overruns.

When it comes to the cost of plug-in vehicle drivetrain components—including motors, power electronics, and accessory drive systems—the supply chain is

largely in place and being developed. As in the case of batteries, the largest hurdle for these components to achieve acceptable cost targets will be scale.

The scale that can be achieved in the automotive supply base will depend on the demand created by each automaker's plug-in vehicle development strategy. A typical vehicle platform is replaced every five to seven years. If auto manufacturers were to adopt a plug-in vehicle strategy, but were to roll out grid-enabled vehicles incrementally on this lifecycle basis, it would take two decades, at best, to turn over their product portfolio from predominantly IC engine-based vehicles to predominantly GEVs. This approach would ensure a long wait for suppliers throughout the value chain to achieve the scale needed to dramatically reduce cost. Meanwhile, these suppliers would be stranded with the large investments they made in order to develop products and manufacturing capacity for electric vehicles.

However, the automakers would also face the quandary of high investment costs if they attempted to roll out GEVs any faster. Since the technology behind vehicle electrification is transformational rather than incremental, the expected research and development costs for a new plug-in vehicle platform—as compared to the costs for another incremental improvement to an IC engine vehicle platform—will be much larger and nearly impossible to finance for simultaneous large portions of the product portfolio. Compounding this investment need are the associated costs of retooling the entire manufacturing process chain to produce the new products. The Department of Energy's \$8 billion in loans to Ford, Nissan, and Tesla—though seemingly large—are really only sufficient to develop and re-tool factories to produce three models of electric vehicles, a relatively tiny number compared to the several hundred vehicle models on the market in 2009.

Retooling an automobile plant to produce GEVs requires time and several hundred million dollars.

RETOOLING

2.3 Charging Infrastructure



Electric vehicle supply equipment will be needed to charge the battery in grid-enabled vehicles once depleted. While a substantial portion of charging can be done overnight at home, public charging options will provide drivers with added confidence and flexibility. With limited exceptions, public charging infrastructure does not exist today.

THE NATURE OF THE REFUELING CHALLENGE FOR GEVS

For the past hundred years, the consumer automobile experience has been relatively consistent in certain key respects. Consumers bought cars from dealers and drove and parked wherever and whenever they wanted. With rare exceptions, refueling options were fast and almost limitless, requiring no advanced planning.

The widespread adoption of electric vehicles will require some important shifts from this model. Based on existing battery technology, both PHEVs and EVs will require relatively frequent recharging in order to benefit from electric propulsion. Because PHEVs will maintain the use of an internal combustion engine, the recharging issue is less of a constraint to mobility (though to the extent that PHEVs rely on gasoline, the payback period on consumers' initial investment will be lengthened). Pure electric vehicles, on the other hand, will most certainly require reliable access to charging units while drivers are carrying out daily commutes and other trips that extend beyond the base range of the battery.

In many instances—though perhaps not all—charging will take hours instead of minutes. There will presumably be a standard plug for all GEVs in the nation, but it is not clear that every car will be able to use every charging facility. It also is not yet clear who will own and operate the charging facilities, who will provide and be paid for the electrical power, or on what terms and at what rates it will be sold.

Overnight charging at home will obviate some of the need for public charging, but—especially at the outset—accessible public charging facilities will be of critical importance in order to increase consumer confidence. Level II EVSEs will support routine charging. Level III chargers will provide fast convenience charging as well as charging for vehicles that are travelling beyond the charge-depleting range of

GEVs will move beyond the current petroleum-based refueling system. This will enhance energy security, but will also require thoughtful investment in charging infrastructure.

their batteries without time to stop for slower charges. Moreover, market participants will need to determine how best to ensure access to overnight electric vehicle supply equipment for consumers without dedicated private parking spaces.

In sum, three key points are clear: First, some amount of public and private charging infrastructure will be necessary to support widespread deployment of GEVs. Second, the costs for constructing a public charging network will be substantial. And third, while consumers will not buy vehicles in the absence of charging infrastructure, private companies will be hesitant to build recharging spots without assured demand.

2.3.1 Understanding Charging

The vehicle charger is the device that connects the vehicle to the electrical grid and through which the vehicle's battery is charged. Efforts to standardize chargers, already underway, will be important to ensure network interoperability.

The term “charger,” as it is used in common parlance when referring to electric vehicles, is a bit of a misnomer. For Level I and Level II charging, the actual charger is located on the vehicle itself. The device that the vehicle connects to is referred to in the technical literature as electric vehicle supply equipment, or EVSE. Level I EVSEs are unique cord sets that integrate the EVSE and its required safety functionality into a box connected in-line with the cord, and which can plug into a traditional 110 volt plug with a dedicated 15 amp circuit. Level II EVSEs need to be mounted and wired to an electrical panel at 220 volts.

Several safety issues will require the use of EVSEs instead of simple cords that connect an outlet to a vehicle. Properly designed EVSEs will ensure that vehicles are properly connected and grounded before

power begins to flow; they will prevent a driver from pulling away while the vehicle is still plugged in; and for batteries that have out-gassing, they will necessitate proper ventilation for charging.

In addition to the safety concerns, EVSEs will, depending on their level of intelligence, ease the integration of plug-in vehicles into the grid and offer consumer benefits. Simple EVSEs can control charging start time. More complex units enable variable charge control based on pricing or grid loading; process user identification and payment; handle vehicle-specific metering; enable vehicle diagnostic reporting; and in the future will control vehicle-to-grid capacity, among many other novel, and as yet unimagined, functions.

There are different levels of charging based on the power available. The charging levels in the United States are governed by a specification published by the Society of Automotive Engineers (SAE), a professional organization that is responsible for developing a wide range of automotive standards. The specification, entitled J1772, defines Level I and Level II charging as well as the interface between the vehicle and the EVSE. Level I charging is specified for the NEMA outlet that most Americans are familiar with—the traditional home plug. This charging is relatively slow, with a maximum of 120V and 12A. At 1.8 kW, a 30 kWh battery in a pure EV could take 15 hours to charge, depending on its initial state of charge. Smaller PHEV batteries would, of course, take less time, with the Chevrolet Volt specified to take approximately eight hours to charge at Level I.

Although Level I charging may be a sufficient solution for many PHEV owners, the lengthy charge times that are necessitated by the much larger EV batteries will likely convince most consumers to opt for higher power Level II charging. Level II charging is specified at between 208 and 240 volts (the voltage used in many homes by electric clothes driers, electric ovens, or well pumps). With the higher power used in Level II charging, EVSEs will have to be permanently mounted.

Though Level II EVSEs are specified for charging at between 12 and 80A, in practice, few vehicles will be able to charge at the maximum amperage rating; most vehicles are being designed to accept a Level II charge at no more than 30A. Automakers are presumably making a trade-off between customer preferences on charging times and the cost and weight associated with larger capacity chargers. For example, the Nissan LEAF, with a 24 kWh battery pack, is expected to take between four and eight hours to charge with a 240V supply.

It should be noted that Level I and Level II charging utilize the same connector interface to the vehicle. The plug that actually plugs into the car is unchanged between the levels. What is different is how those plugs are connected to the grid.

SAE has defined direct current (DC) fast charging, commonly referred to as Level III charging, as well. Designed for commercial applications, these chargers range from 30 kW to 250 kW with the goal of a complete charge in less than 10 minutes. Level III chargers will be significantly more expensive than Level I or II chargers and are expected to be available at commercial charging establishments. As an example, a Level III charger operating at 50 kW can fully charge a 24 kWh battery in approximately 25 minutes and could cost between \$25,000 and \$50,000. This happens to be about the same as the cost of a typical gas station pump. Fast charging rates will likely not be limited by the details of the standard, but rather by grid infrastructure capability and the tolerance of the battery chemistry.

In addition to the specifications defining the physical connectors, interfaces, and power levels, SAE is also developing specifications that will govern the communication between vehicles and the grid. These publications are also still being written as of October 2009.



A Google employee sends a computer e-mail near one of the many electric cars owned and leased by the company at its Mountain View, California campus. The electric hybrid cars are charged from rooftop solar panels.

2.3.2 Charging at Home

For drivers with access to a dedicated outlet, the most convenient time to charge their GEV will be overnight at home. This will place minimal strain on the grid and offer other important benefits as well.

The underlying assumption in the charger specifications being developed is that the vast majority of plug-in vehicle charging will take place at owners' homes. Most vehicles sit idly overnight at homes, which could provide ample opportunity to supply consumers with the charge levels required for using their PHEVs or EVs.

Important shortcomings of home charging will need to be addressed before grid-enabled vehicles can be widely adopted, however. First, most consumers would probably prefer the convenience of Level II charging in their homes. However, a large percentage of homes will require the installation of a 220 volt plug in their garages or parking shelters. This installation is an additional cost that will extend the payback period for GEVs. Current estimates for Level II installation at home suggest a range from \$500 to

\$1,500 if an electrical panel upgrade is not needed, and around \$2,500 if an upgrade is required.³⁵

Perhaps of greater concern is the fact that not every household has access to a dedicated parking space. For consumers who currently rely on street parking, overnight home charging will be a more difficult proposition. Existing data suggests that this will be a particularly significant impediment to GEV adoption in the Northeast, the South, and generally in inner cities.

³⁵ Pacific Gas & Electric Company, "EV Charging in Single Family Residences," Electric Vehicle Infrastructure Installation Guide," Chapter 4 (March 1999), available at www.pge.com/includes/docs/pdfs/shared/environment/pge/cleanair/ev6pt4.pdf, last accessed on October 28, 2009.

FIGURE 2I HOUSING UNIT CHARACTERISTICS, 2005

	SHARE OF OCCUPIED HOUSING UNITS	% WITH GARAGE OR CARPORT
TYPE OF HOUSING UNIT		
New Construction (less than or equal to 4 years)	5.5%	79.3%
Manufactured/Mobile Homes	6.4%	30.3%
With Physical Problems	5.7%	37.9%
All Other	82.4%	65.8%
GEOGRAPHIC LOCATION		
Northeast	18.7%	49.0%
Midwest	22.9%	72.0%
South	36.5%	54.8%
West	21.9%	77.6%
TYPE OF LOCATION		
MSA - Central City	29.2%	53.7%
MSA - Suburbs	48.5%	69.1%
Outside MSA	22.3%	60.4%

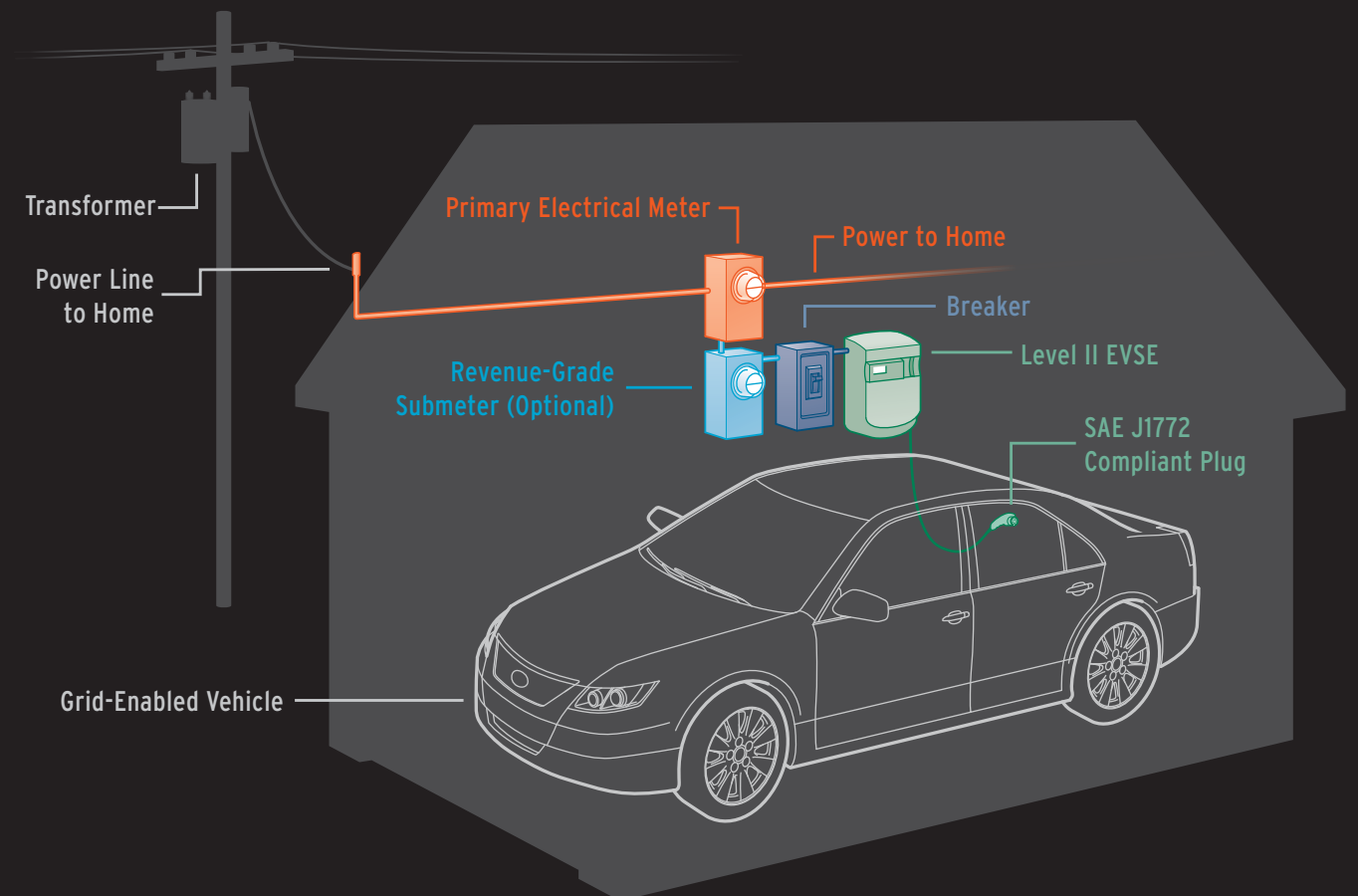
Source: EERE, Transportation Energy Data Book

FIGURE 2J

Home Charging Configuration

GEV owners will typically install an EVSE device in their garage, carport, or near their dedicated overnight parking spot. A Level II charger, operating at 220 volts, can be mounted on the wall of a garage, plugged into an existing 220 volt outlet or wired directly into a home's electrical panel.

The EVSE may be submetered so that electricity used to charge a vehicle may be subject to different rates. A submeter could also be integrated into an EVSE or even the vehicle. The cord will run from the EVSE to a J1772 standard plug, allowing any vehicle to charge at any Level I or II charger.



2.3.3 Public Charging

Reliable access to a network of public charging equipment will provide GEV owners with confidence and flexibility. Especially in the early stages of GEVs and batteries, consumers will likely demand the ability to recharge frequently.

As important as access to home charging will be for achieving high rates of GEV deployment, public charging is arguably even more important for moving past the very early stages of GEV adoption. There are at least two reasons for this.

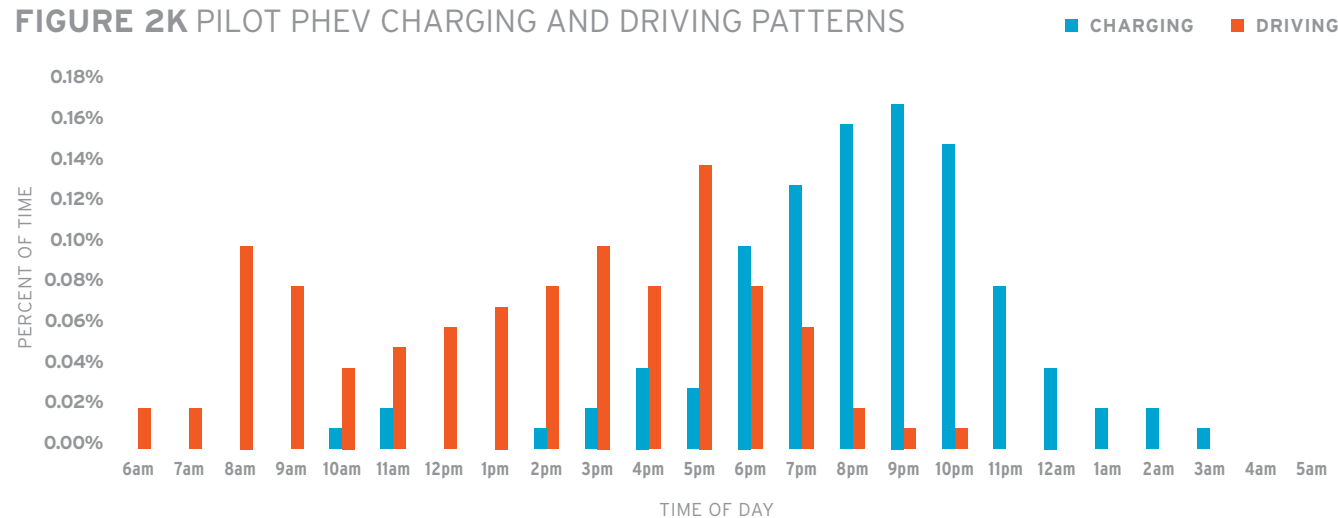
First, drivers are accustomed to being able to fill up using the ubiquitous gasoline infrastructure developed over the last 100 years. Inability to do so will generate significant hesitancy for most consumers and will hinder adoption of electric vehicles. This hesitancy is most often termed “range anxiety,” and obviously applies to pure EVs more than to PHEVs. It will be in the interest of all market participants to ensure that consumer range anxiety is mitigated. One way to do this could be to roll out an expansive and pervasive public infrastructure, though important questions about utilization rates and power prices will determine the profitability of such an infrastructure for private owners.

A second factor that highlights the importance of public recharging infrastructure relates to anticipated patterns of GEV refueling. In essence, without access to Level II EVSEs or Level III chargers away from the home, most drivers will be inclined to plug in each time they return home. For a large percentage of drivers, this will be

at the end of the work day. Pilot testing carried out by the Idaho National Laboratory largely confirms the notion that, in the absence of accessible public recharging equipment, consumer charging tends to the hours between 6:00 pm and 10:00 pm. Figure 2K displays charging and driving patterns for nine converted Toyota Prius vehicles operating in five states during January and February 2008. Despite the extremely small scale of testing, the exercise confirms that while driving is spread throughout the day, charging is concentrated in the evening.

Two distinct issues arise in such a ‘home only’ charging pattern. First, concentrating charging to a few hours has the potential to place heavy strain on the electric power sector, particularly at the local distribution (transformer) level. A number of emerging smart grid applications could mitigate this risk, but it would be preferable to spread charging somewhat more evenly. Second, because PHEVs will generally have smaller batteries than pure EVs, it is conceivable that they will need to be charged somewhat frequently in order to obtain the fuel-economy benefits of all-electric driving. In both cases, access to a reliable network of public charging equipment will enhance the operability of grid-enabled vehicles.

FIGURE 2K PILOT PHEV CHARGING AND DRIVING PATTERNS



Source: Idaho National Laboratory

2.3.4 Public Charging: Who Will Pay?

Financing public charging infrastructure is a challenge. In the absence of access fees, which make GEVs less cost effective for the user, it is unclear how the charging infrastructure can be built.

The need for public infrastructure is obvious and was reflected in the Department of Energy’s grant to companies to deploy public EVSEs in several regions. But an important problem is implicit in this award: who will fund charging infrastructure? The government has shown its willingness to fund the first \$100 million of infrastructure, but the next \$10 billion is less likely, especially since the federal government has not yet declared public charging infrastructure to be a national priority.

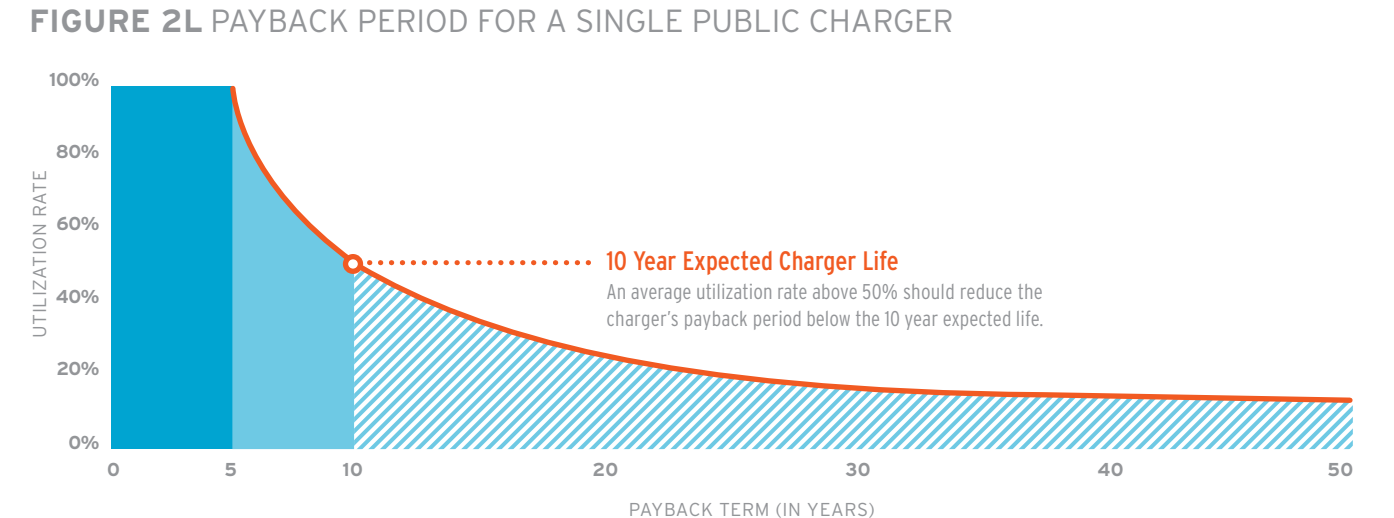
GEV advocates have suggested that private firms should install public charging infrastructure wherever consumers may need it. However, what has not been reliably demonstrated is a profitable business model that would encourage anyone in the private sector to invest in the installation of such a network. In order for plug-in vehicles to be economic for consumers, they need to be able to charge their vehicles inexpensively; in fact the only way to recover the cost of an expensive battery is to defray it over time with comparatively cheap electricity. This may serve as an upper bound on the price consumers are willing to pay to charge their vehicles. The readily available substitute of home charging also places an upper limit on what consumers will be willing to pay—and private entities therefore

could charge—for public charging on a regular basis. This may be why large domestic infrastructure providers such as Eaton and GE have only hesitantly ventured into this market or avoided it altogether.

Firms today are selling Level II public EVSEs for around \$2,000 to \$3,000. A single EVSE charging at 5 kWh per hour could in theory provide 120 kWh of electricity per day (or 43,800 kWh per year) to GEVs. Given that they will not be used continuously, however, the true amount is likely to be considerably lower. Average retail electric prices in the United States vary substantially by region, but the U.S. average is approximately 10 cents per kWh (as of October 2009). If an operator were to charge a premium of 10 percent, they would receive revenues (less overhead) of just \$438 per year. For average installed costs of \$1,875, the payback period would be five years—and this assumes continuous (and obviously unrealistic) use of the charge point.

More realistically, if it is assumed that Level II charge station owners can recoup a 20 percent margin on the cost of electricity consumption, that any individual charge station is utilized 20 percent of the time, that there is a nominal cost of maintenance, and—very generously—that we can ignore the cost of installation,

FIGURE 2L PAYBACK PERIOD FOR A SINGLE PUBLIC CHARGER



Source: PRTM Analysis

then the payback period on the investment in a single charge station exceeds 25 years. Increasing utilization provides some relief, but a station would have to exceed 50 percent utilization to reduce the payback to less than 10 years, and the owner must still pay the cost of installation, which can run more than the cost of the charger itself.

Level III chargers provide drivers with a fast charge, filling in minutes a battery that would take hours to charge at Level I or II rates. Level III chargers, however, are significantly more expensive than Level II chargers and constitute a more significant instantaneous load per charge. Therefore, they must be located in commercial areas. Just as with Level II public EVSEs, it is unclear how one could install and recoup the cost of a Level III charger, as the higher price it would charge makes a GEV less economic. Nevertheless, drivers will certainly need fast charges and will be willing to pay extra for them. The only real question is how much and how to develop a profitable business model around them.

Some have suggested that private firms will choose to install chargers not for the monetary reward, but as an incentive to lure customers to their business or to offer perquisites to employees. This may hold true in the near term; we have seen this reasoning in action with stations installed at hospitals, city halls, private retailers, and even

a McDonald's. Relying on this model of deployment, however, will almost certainly result in a network that is in no way efficiently designed. Instead of placing chargers where consumers need them most, such a system would result in an irregular, undependable, and unevenly distributed network that will do little to ease drivers' range anxiety.

Further, depending on such a model would be short-sighted when looking forward to a future with widespread vehicle adoption. Though retailers or employers may be convinced to give away electricity to GEV owners while vehicle volumes are small, when the country reaches a high penetration of plug-in vehicles, and the electricity demand for an entire parking lot becomes more costly, most rational firms will refuse to continue to assume that burden without some direct monetary benefit.

Some may point to utilities to provide charging infrastructure, and this may be a viable alternative, but a few problems must be overcome first. Utilities currently cannot add the cost of chargers to their rate base; such a cost would therefore degrade their margins. Nonetheless, some utilities, such as Southern California Edison and Portland Gas and Electric, have taken on the burden of installing small demonstration projects of charger networks. But again, these demonstration projects are far from the necessary infrastructure needed to support wide-scale adoption of EVs, and it is unlikely that any utilities will be willing to accept this cost burden unremunerated.

Even if utilities were permitted to allocate the cost of charger purchase and installation into their rate base, the impact of this decision has the potential to negatively impact public perceptions of GEVs. Plug-in vehicles—with their initial high price tags and with high-end vehicles like the Tesla Roadster occupying the public mindset—may be viewed early on as the domain of the affluent. When the rate base is borne by all consumers, even the poor, the inclusion of charging infrastructure into pricing could be interpreted as the poor subsidizing the luxuries of the wealthy.

The most obvious way to drive down infrastructure costs, certainly initially and likely thereafter as well, is to take advantage of economies of scale. There are at least four significant opportunities with respect to the deployment of charging infrastructure. First, public charging facilities have economies of scale in installation. To the extent that multiple chargers are installed in a single parking lot or on a single street, it is less expensive on a per-unit basis than installing individual chargers. Multiple chargers can be purchased at once. They can be connected to the power grid by a single power line and installed at once by an installation crew. Second, utilities will likely have to upgrade their information technology equipment in order to support advanced billing schedules and to control the chargers in order to maintain reliable operation of the grid once significant volumes of GEVs are deployed. Third, there may be economies of scale in in-home charger installations. Fourth, if companies other than utilities or power marketers are permitted to re-sell electricity at the retail level, they may develop new and creative approaches to pay for the charging infrastructure.



2.3.5 Striking a Balance?

The greater the number of public chargers deployed, the less each of them might be used. Determining how many are needed to meet drivers' needs will be critical in making the system work.

An issue of expected consumer behavior muddies the picture further. While counterintuitive, it is likely that the more public infrastructure is installed and available, the less it will actually be used. The Tokyo Electric Power Company (TEPCO) had a fleet of electric vehicles with charging stations located mostly at the home fleet depot. These EVs would typically come back to the depot with very high states of charge remaining, often greater than 50 percent.

TEPCO then installed a network of fast chargers throughout the city. The results of this installation were surprising. Rather than using the public charging spots to continually top off their batteries, just knowing the spots were there made drivers more comfortable with their vehicles and reduced their anxiety over range. The EVs in the fleet began coming back to the depot with very low states of charge and the driving patterns of the users showed much broader and widespread routes throughout the city, as opposed to the constrained routes they had previously driven.

The TEPCO exercise raises an important issue. Particularly for pure electric vehicles, it is widely assumed that a pervasive network of public charging infrastructure will be needed to satisfy consumer demands for refueling. Such a network would be designed to allay concerns about battery range and make consumers more comfortable about purchasing an EV. However, as consumer confidence grows, it is entirely possible that Level II EVSE or Level III charger utilization rates will be lower than expected. Given the cost of the recharging units, it will be important for all stakeholders to think carefully about how best to deploy infrastructure and in what quantities.

As an example, consider the range of estimates for Level II public recharging infrastructure that would be required to support the GEV volumes proposed in Section One of this report (14 million GEVs on the road in 2020 and 123 million in 2030). Three Level II EVSE scenarios are considered here:

1. A maximum case in which a very high ratio of chargers to vehicles is required;
2. A minimum case; and
3. An expected case

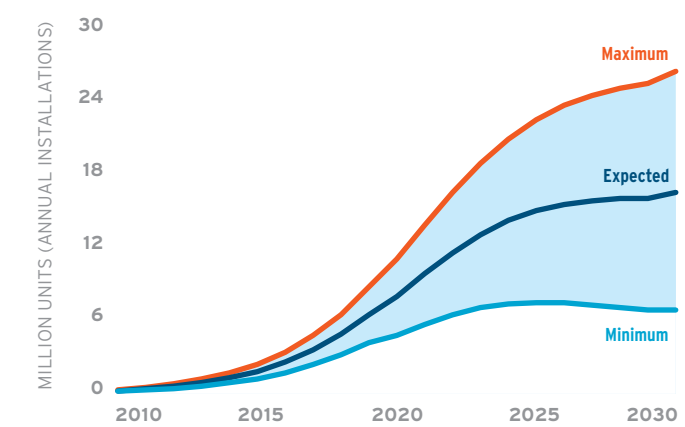
Figure 2M contains the assumed EVSE ratios across all scenarios. Figure 2N displays the required number of annual infrastructure installations to support the GEV volumes in each of the three cases assuming a standard attrition rate of 10 years.

The ratio of public EVSEs to GEVs is critically important for assessing the total costs of infrastructure deployment. As can be seen in Figure 2O, by 2030 the cumulative cost of public EVSEs varies by nearly \$200 billion from the minimum to maximum ratios. Based on the TEPCO exercise, it seems clear that investment in public infrastructure will need to be carefully designed.

FIGURE 2M PUBLIC CHARGERS RATIOS

	2010	2020	2030
Expected Public Chargers per Vehicle	2.0	1.5	1.0
Maximum Public Chargers per Vehicle	2.5	2.0	1.5
Minimum Public Chargers per Vehicle	1.5	1.0	0.5

FIGURE 2N PUBLIC CHARGERS NEEDED TO SUPPORT GEV VOLUMES



Source: PRTM Analysis

Building an efficient public charging network will require careful planning.

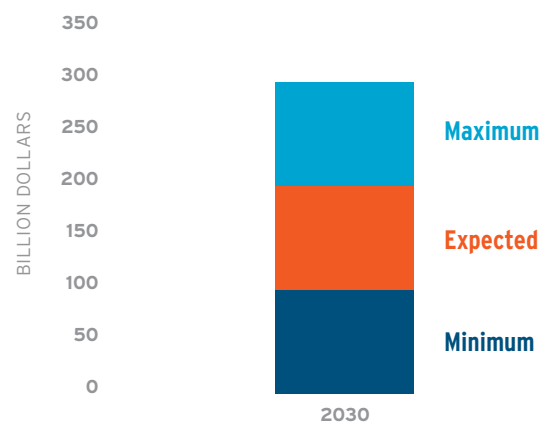
THE NETWORK OPERATOR MODEL

Much of the current discussion regarding electric vehicle supply equipment and EV chargers pre-supposes the presence of a separate EVSE provider—either specialized firms or utilities, for example. Both of these models face significant challenges, particularly with regard to monetizing the substantial upfront costs associated with infrastructure installation. Certainly, public policy solutions exist to address these issues, but some GEV industry participants are actively developing alternative models.

One such alternative is the network operator model. Currently, the primary entrant into this space is Better Place. Better Place aims to be a complete end-to-end provider of the electric mobility experience for consumers. The company envisions dense urban clusters of pure EVs blanketed by charge spots in front of homes, offices, shopping centers, and anywhere vehicles pause. Along major arteries connecting cities, Better Place proposes to construct battery replacement stations that can remove a depleted battery and replace it with a fully charged unit in less time than a typical gasoline fill-up.

Better Place aims to incorporate the battery and infrastructure expenses for GEVs into the company's cost structure. In turn, Better Place customers would pay subscriber fees based on mileage 'consumption.' These fees would be higher than the cost of electricity alone, but less than the cost of gasoline. Despite these higher costs for consumers, one key advantage of the network operator model is that it presumably could operate profitably while deploying infrastructure.

FIGURE 20 CUMULATIVE COST OF PUBLIC CHARGERS



Source: PRTM Analysis

This problem further demonstrates the challenge of installing a public charging network. Early on, a ubiquitous network of public chargers may assist in minimizing consumer anxiety about battery range. It may also be important to deploy chargers along lengthy interstate corridors in order to provide recharging opportunities for longer trips. But clearly a headlong rush to deploy nationwide infrastructure could be unnecessarily costly.

These realities can only be surmounted in one of three ways:

1. New, innovative firms will emerge that develop unique business models to mitigate the infrastructure problems;
2. The installation of infrastructure will become a national issue addressed on a federal level; or
3. Some hybrid model will blend innovative business solutions with public policy support.

A hybrid model may take a form similar to the agreements made with cable television providers. These entities were given monopoly rights in specific territories but were obligated to install a complete infrastructure to earn that monopoly right. Regardless of the method chosen to invest in the plug-in vehicle infrastructure, the industry will certainly fail to develop without such an infrastructure. If the United States concludes that vehicle electrification is the primary path for energy security, in the absence of private sector willingness to develop the required charging infrastructure, the installation of that infrastructure might become a federal responsibility.



2.4 Electric Power Sector

The deployment of GEVs represents an enormous opportunity for the electric power sector to establish an entirely new category of customers. While much of the infrastructure is in place to meet GEV needs, utilities will have to upgrade their information technology, replace some transformers, and seek innovative regulatory treatment so that they can serve this new business.

GEVs represent an enormous opportunity for the nation's electric utilities and power marketers. Light-duty vehicles are the largest portion of the most significant sector of the economy that is reliant primarily on some form of energy other than electricity. Utilities and power marketers should be eager to convert the LDV fleet to electricity, in whole or in part. The nation currently consumes about 4.1 trillion kWh of electric power each year. If 150 million light-duty GEVs each consume 8 kWh of power a day, that would represent an additional 440 billion kWh of power consumed each year. Depending on the manner in which that power is consumed, there may be relatively little need for additional generating capacity; much of the vehicle charging can take place during off-peak hours, when a significant portion of the nation's generating capacity typically is idle. Moreover, by flattening the load curve and increasing the utilization rates of existing power

plants, utilities should be able to spread their fixed costs over a greater volume of power and reduce maintenance costs, perhaps lowering costs for all of their customers.

Yet, while the potential of adding millions of GEVs represents a great opportunity for utilities, it also requires them to address several challenges. Utilities will have to invest in new IT infrastructure and develop new rate plans to facilitate the addition of GEVs to their customer base. They also will have to upgrade distribution level transformers to ensure the reliable delivery of power to homes and other locations at which drivers recharge electric vehicles. Regulatory reforms are also required. Addressing these challenges, however, is well within the capabilities of most utilities, and payoff for the utilities and the nation will be significant.



The bright lights of Detroit and dimmer lights of Windsor, Ontario.

2.4.1 Hardware

While charging, GEV power demand can rival that of an average U.S. home. To reliably serve large GEV volumes in the short to medium term, the electric industry may need to upgrade neighborhood transformers.

The nation's electrical system is comprised of generating plants, transmission lines, and distribution lines and equipment. Electric power is produced at generating plants, typically at relatively low voltages. It is then stepped to higher voltages for transmission over high voltage lines that carry large volumes of electricity with minimal line losses to the general areas where electricity is consumed. The transmission network connects to the distribution network at substations that use transformers to reduce the voltage for distribution to communities and neighborhoods. Shortly before electricity is delivered to consumers, additional transformers reduce the voltage further (in the case of residential customers, to 220 volts). The last transformer on the network in a residential area might typically serve between five and 15 homes.

Electricity is different from other commodities in that it cannot be stored easily or economically in any

appreciable quantities. It must be generated, transmitted, and distributed the very moment it is needed. Accordingly, the electric delivery system must operate in a nearly perfect balance in which the volume of power being generated must match the volume of power being consumed at every moment. If too much power is being generated, the frequency of the power on the grid will rise above acceptable limits; if too little, the frequency will fall.³⁶ Shortages or surpluses of power at any given moment, depending on their size and location, can lead to instability in the system, culminating in blackouts that have the potential to cascade across large regions as generators disconnect from the system. Because electricity is delivered almost at the speed of light—186,000 miles per second—problems

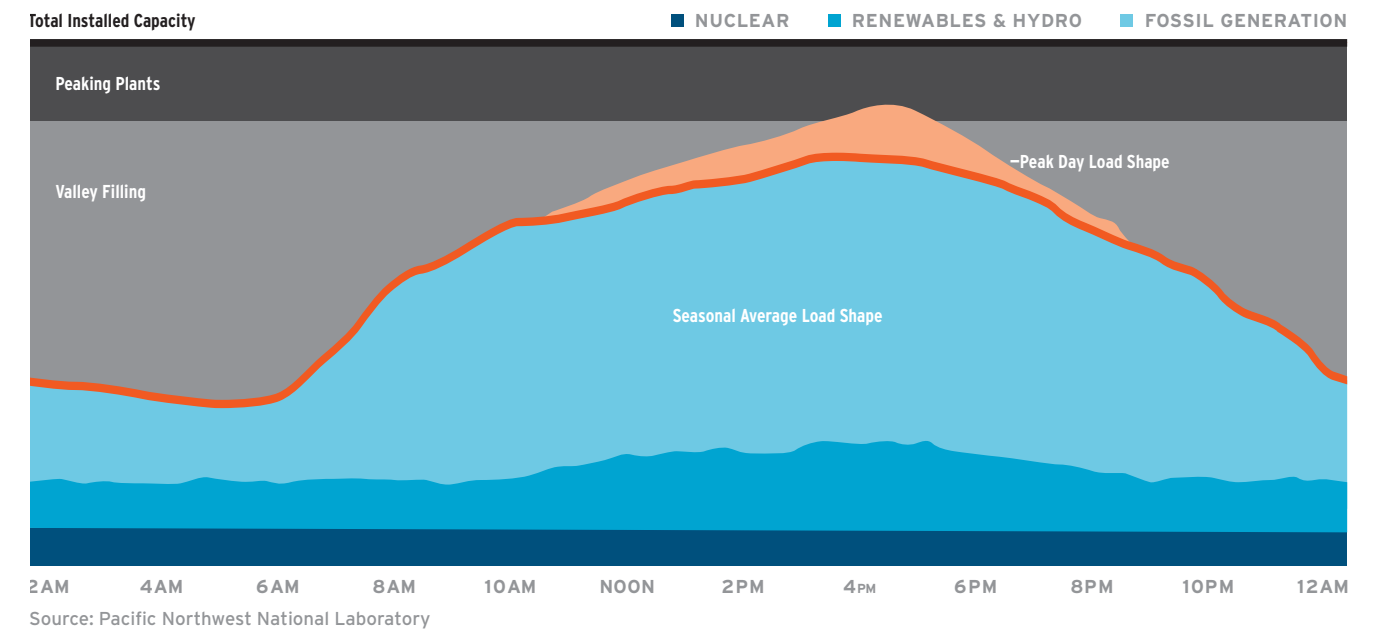
³⁶ Frequency is the number of complete alternations or cycles per second of an alternating current. It is measured in Hertz. The standard frequency in the US is 60 Hz. In some other countries the standard is 50 Hz.



Pylons at a power generation plant.



FIGURE 2P STYLIZED LOAD SHAPE FOR ONE DAY DURING PEAK SEASON, GENERATION DISPATCH, AND INSTALLED CAPACITY



can occur quickly, before anyone can intervene to stop them. (The August 2003 outage, for instance, cascaded from Ohio to New York in minutes.)³⁷

The entire system must be constructed with the capability to generate and deliver power at the level required during the periods of greatest demand. In fact, to meet reliability requirements, American utilities maintain substantial generation capacity, or margin, over forecast peak. In 2008, utilities had a capacity margin of between 12 and 20 percent during peak demand.³⁸ The system, therefore, rarely operates at its maximum capacity (and even when it hits peaks, it does so for only short periods of time). Most systems experience both daily peaks and seasonal peaks. Daily power consumption tends to peak late on weekday afternoons when significant numbers of people are still at work and as many others start arriving home. Seasonal peaks tend to occur in the summer (due to air conditioning load) and the winter (due to heating load). The highest peak periods overall tend to be late in the afternoon on hot summer days. Yet, even on

days on which demand nears system capacity, it falls sharply overnight as people go to sleep and temperatures drop.

The result is that for much of the time, the electrical system has significant volumes of excess generating capacity. Much of this spare capacity can be used to generate electricity to charge GEVs. In fact, the system has sufficient generating capacity to charge vehicles for the early and medium stages of deployment. Likewise, there is sufficient transmission and distribution capacity to deliver electric power to vehicles for charging, with two important exceptions.

First, the last transformer through which electricity moves prior to being delivered to residential customers reduces the voltage to 220 volts. These transformers typically serve between five and 15 homes, often with a relatively small margin of excess capacity. While GEVs are plugged in and actually charging, they represent a significant power draw for most U.S. homes. A Level II charger operating at 220 volts on a 15 amp circuit is expected to draw 3.3 kilowatts of power, a load that is similar to the average load in a typical home. In other words, the addition of a GEV to a circuit is roughly the equivalent of adding a substantial portion of another house's worth of load to the circuit. (On a 30 amp circuit, a Level II charger can draw 6.6 kW of power, far exceeding a typical

³⁷ U.S.-Canada Power System Outage Task Force, "Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations," April 2004, available at reports.energy.gov/BlackoutFinal-Web.pdf.

³⁸ North American Electric Reliability Corporation, "2008 Long-Term Reliability Assessment," (Table 13a) (October 2008), available at www.nerc.com/files/LTRA2008v1.2.pdf, last accessed on October 28, 2009.

home's average load.) While it is true that much vehicle charging would take place overnight—when loads in homes are typically low—it is generally understood by the industry that plugging one or more GEVs into a single circuit could exceed the transformer's limits, causing it to fail and resulting in a loss of power for customers served by that transformer. This concern has been confirmed by research at the Electric Power Research Institute.³⁹

In order to support the reliability of the electrical grid in a GEV ecosystem, utilities will have to take steps to ensure that they can deliver power over the last few feet of power lines from the neighborhood transformer to a home. Upgrading neighborhood transformers should be a routine system upgrade for any distribution utility. Moreover, rates for distribution services are regulated in every state by state public utility commissions (PUCs); the costs of such distribution level infrastructure are typically incorporated into a utility's rate base and recovered from their customers subject to PUC approval. There is nothing unique about this type of upgrade; utilities should be able to perform them without undue trouble.

In a study conducted by EPRI, plugging in just one PHEV to charge at 220 volts overloaded 36 of 53 transformers examined during peak hours and five of 53 transformers during off-peak hours. It is, therefore, important to identify where GEVs are parked and charged so that utilities can be prepared to make the upgrades necessary to maintain reliable service.

Utilities can make educated guesses regarding where GEVs will be parked, especially in the early deployment, based on socioeconomic status of their customers. Some utilities have, for instance, already identified the location of HEVs in their service territories, and assumed that HEV owners will be among the first purchasers of GEVs.

While such an assumption may make sense, it will not be helpful once GEVs expand beyond the universe of early adopters. What will be required is a more

systematic approach to identifying the residential charging locations of GEVs.

Several different approaches are possible. States could require that GEV purchasers provide dealers with an address where a home charger will be used so that the dealer may provide the information to the local utility. GEVs will be identifiable by their VIN numbers; therefore, state departments of motor vehicles could provide to local utilities the address at which GEVs are newly registered. Ultimately, the means by which notification occurs is of less importance than the fact that it actually occurs. While no action is necessary now, if utilities are unable to address this challenge on their own, state or federal assistance could be necessary.

The second issue facing utilities is that, in addition to the deployment of Level I and Level II charging facilities, Level III fast-charging facilities will also be deployed. Such facilities will be capable of charging a battery at a fast rate, such that a fully discharged 30 kWh battery could be charged to 80 percent of capacity in 10 minutes. In order to "push" that much power through the charger so quickly, they will require three-phase power, a higher grade of electric power generally limited to heavy load use. Utilities will have to work with commercial fast-charging stations to ensure that those facilities have sufficient power to operate without affecting the reliability of their neighbor's electric power supplies. Such upgrades are routine, and their cost should largely be attributable to the commercial facilities on whose behalf they are constructed.



2.4.2 Software

In order to manage demand for electricity and take full advantage of the energy storage capabilities of GEVs, utilities will need to upgrade their IT infrastructure.

Utilities will need to upgrade their IT infrastructure so that they and other market participants (such as electric market retailers or EV network operators) can manage the vehicle charging process as well as to facilitate billing for electricity used in vehicle charging. Whereas charging vehicles during off-peak hours is a potential boon to utilities, the capability to utilize existing spare capacity can only work with IT infrastructure that allows the utility (or other market participants) to turn vehicle chargers on and off in order to help shape the system's load. Not only do utilities not want everyone to plug in their GEV during peak hours, they also will need to ensure that the vehicles do not all begin charging at the same time. Given that an average EV with a 30 kWh battery may take only five hours to charge (with a Level II charger at 6.6 kWh), and an average PHEV with a 16 kWh battery may take less than three hours to charge, utilities and network operators will want to allow customers to schedule vehicle charging during off-peak hours to benefit from advantageous pricing and to maintain as steady a load as possible. They can also ensure that vehicles on the same transformer charge at different

times in order to reduce the likelihood of overloading a particular transformer. In some instances, utilities may also be able to initiate charging to take advantage of the availability of renewable resources.

Among the tools that utilities will need to use in order to help manage demand from GEVs is the use of price signals. Utilities will need the capability to either bill GEV customers subject to a rate schedule different than other customers, or to offer them time-of-day pricing. By charging high rates during periods of peak demand and low rates during off-peak hours, utilities can help shift load from peak to off-peak times. With 40 million smart meters expected to be deployed in the United States by 2015, the metering infrastructure to support GEVs will already be in place for many consumers. However, beyond the smart meter, utilities will still need the IT infrastructure to allow for communication with grid-enabled devices, allowing customers to access advanced billing using time-of-day rates or other variable rate structures.

TRANSFORMERS
In many cases, utilities will need to upgrade transformers to support GEVs.



A transmission grid controller monitors grid performance from a control station.

³⁹ EPRI, "Impact of Plug-In Hybrid Electric Vehicles on Utility Distribution Systems," (August 2009).

2.4.3 GEVs and the Smart Grid

The eventual deployment of smart grid technology is a key milestone in the ability of utilities to manage GEV interface with the power sector. A responsive and intelligent grid will also serve to enhance the GEV experience.

The ability to control the GEV charging process and the flexibility to offer innovative rate structures for electricity would only be possible with the development of a ‘smart grid.’ Moreover, these functions only represent a small portion of smart grid capabilities.

The smart grid is a system that delivers electricity from utilities to their customers using digital technology to save energy, reduce costs, and enhance system reliability. On the supply side of the equation, smart grid applications will enhance reliability of the transmission grid, help integrate renewable transmission into utilities’ generation portfolios, improve the quality of power, and improve the efficiency of grid operations. On the demand side of the equation, smart grid technology will help customers adjust their consumption of power, perhaps on an appliance-by-appliance basis, in order to better manage utilities’ load curves, reduce emissions, lower costs, and enhance reliability.

One aspect of the smart grid involves customers’ use of smart meters that not only measure the power consumed, but also the time at which it was consumed and perhaps the appliance that consumed it. In theory, smart meters could also provide real time price signals to consumers. When combined with simple customer interfaces, smart meters could be used to encourage consumers to adjust their consumption of electricity in a manner that reduces costs and enhances system-wide reliability without reducing consumer utility. Part of the challenge faced by utilities and consumers is how to identify a model

that takes advantage of smart grid technology in a way that promotes efficiency of the electric power system while providing consumers with flexibility and lower cost power.

Given its immense promise, the Department of Energy recently awarded \$3.4 billion to accelerate deployment of the smart grid, with DOE-funded projects ongoing in 49 of 50 states. To the extent that this infrastructure is deployed, utilities or power marketers will have the ability to charge different rates for power at different times of day, more closely aligning rates to the cost of the services provided. Eventually, different billing rates for power consumed by different appliances or at different places (in the case of a GEV, a mobile appliance) could be implemented.

As noted above, the smart grid systems to support GEVs represent but a small part of smart grid technology. However, most smart grid technology is interrelated. The IT platform that is needed to interact with GEVs should be based on the same protocols and principles as other smart grid applications. Ultimately, GEVs have the potential to become an iconic symbol of the smart grid, and GEV-related investments in smart grid technology should be made with the same objectives of enhancing consumer experience and control over their energy usage.

The public and private sectors have committed \$8.1 billion to smart grid technology in 2009.



2.4.4 Regulatory Reform

Deploying grid-enabled vehicles at scale will place some additional burden on utilities. While much of this can be managed with investment in new grid hardware and smart grid technology, key regulatory barriers will need to be minimized.

The electric power industry has a long history of government regulation. Some of the practices that are common today will have to be adjusted to accommodate the deployment of GEVs. It is useful, however, to first understand the nature of current regulations in order to understand how they should be altered.

While the utility industry is extremely capital intensive, the marginal cost of serving each additional customer is generally low. In general, a single utility can serve customers more efficiently than multiple utilities, because adding a new customer generally increases revenues while lowering the average cost of serving each customer. Economists refer to this as a ‘natural monopoly.’ Although they may be the most efficient means to serve customers, natural monopolies can engage in monopolistic behavior and earn monopoly profits. Government, therefore, often chooses to regulate natural monopolies, which accept regulation in exchange for a guaranteed rate of return on their capital investment. In the utility industry, retail electricity rates and terms of service for service provided by private or investor owned utilities have historically been regulated by state public utility commissions (PUCs).

Through the 1970s, the system of government regulation of utility rates existed without much attention or fanfare. Though PUCs could disallow the inclusion of expenses in rate bases on which utilities earned government-sanctioned rates of return, costs had been declining over the long term and there was little controversy. The development of nuclear power plants, which were extremely large capital investments, represented a significant break from the status quo.

Cost overruns in the nuclear industry, exacerbated by changes to plants under construction at the time of the accident at Three Mile Island, exceeded \$100 billion for the first 75 plants. State regulators refused to pass all

of the costs along to utility customers, finding that some costs at plants were imprudently incurred, and that in some instances construction of the plants altogether was imprudent. Nevertheless, taxpayers and ratepayers bailed out the industry to the tune of more than \$200 billion in cost overruns for existing plants, and several utilities failed as the result of their investments in nuclear power. This experience led to a sense of conservatism in which utilities were reluctant to make innovative investments; if they succeeded, their rates of return were limited by government regulation, but if they failed, the costs were borne by their shareholders.

As utility rates rose, regulators began looking more closely at new investments in generation and transmission capacity. Rather than routinely approving plans for new facilities, utilities were often challenged to demonstrate why it was not more efficient to encourage conservation than to build more capacity. At the same time, concern was growing about the environmental consequences of energy consumption, placing further pressure on utilities to promote conservation. Today, several states have passed renewable portfolio standards that require the use of certain types of alternative power generation technologies, which typically are more expensive than traditional power generated from coal, natural gas and existing nuclear power plants. As these mandates require the generation of more power from alternative sources, prices are likely to rise to reflect their higher costs.

In the current regulatory environment, utilities are left with two primary challenges related to the deployment of GEVs. First, it is critical that utilities have some assurance that their investments in GEV-related technology will not be treated as ‘imprudent’ by utility regulators. Second, rate structures may have to change in order to both accommodate GEVs and to help integrate their power consumption into utility load curves.

2.4.5 Vehicle to Home and Grid

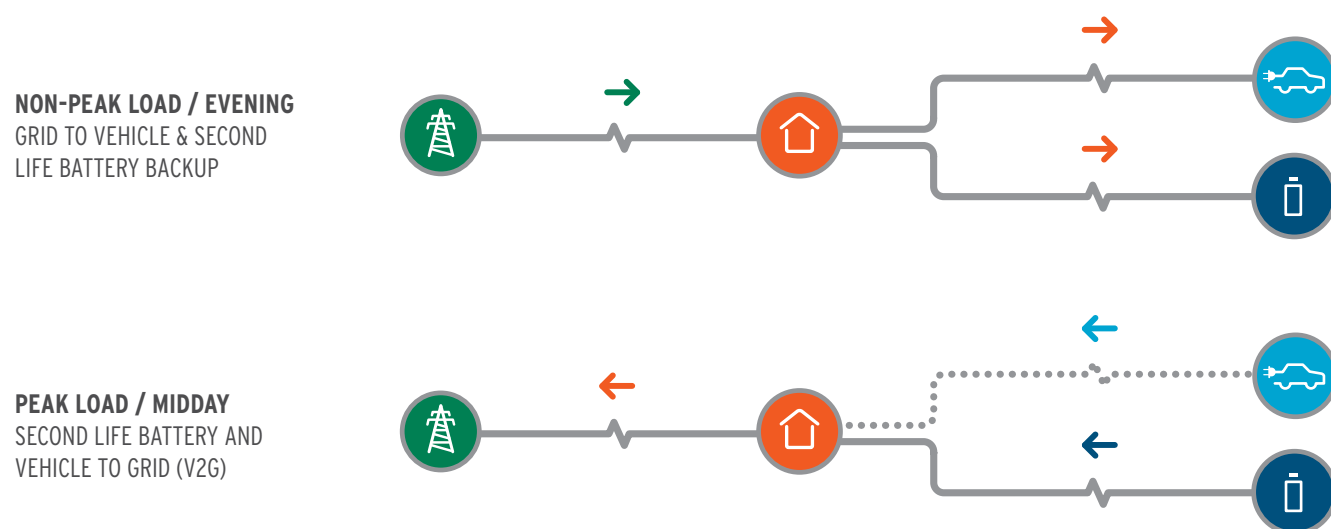
Vehicle-to-home and vehicle-to-grid technologies promise much for the future, but are likely several generations away from mass deployment. Issues more central to deploying GEVs must first be addressed.

In addition to the prospect of using electricity to serve as the primary or exclusive source of power for GEVs, GEVs also present the opportunity to deliver power stored in their batteries back to the electrical grid. Reversing the flow of power from the vehicle to the grid—so called V2G applications—offers the opportunity to provide ancillary services to the grid whenever vehicles are plugged in, to use electrical power stored in vehicle batteries to provide power to the grid during periods of peak demand, and to assist in the integration of intermittent renewable resources into the electrical system.

These applications hold out significant promise for the future. If, for instance, 1 million fully-charged GEVs with an average battery capacity of 16 kWh were discharged at the rate of just 2 kWh, they could supply the grid with 2,000 MW of power for a period of up to two hours. In this example, GEVs would provide the power equivalent of two nuclear power plants while retaining 75 percent of their charge. The ability of GEVs to perform this function could reduce the need to rely on peak power plants.

Despite their promise, however, V2G applications are still many years away from practical application; they are unlikely to appear before the third or fourth generation of GEVs. Prior to the deployment of V2G applications, homeowners (or automakers) would have to install bidirectional chargers, utilities would have to develop the software to control the process in real time, and all participants in the system would have to understand the effect that such practices would have on battery life. As explained earlier, increasing the frequency of charge and discharge cycles can have a significant effect on battery life. It seems unlikely that consumers and automakers would want to risk shortening battery life; applications that might harm batteries beyond their primary responsibility of powering a vehicle would be disfavored until there is a much better understanding of their effect. Nevertheless, as the technology progresses, it is likely that V2G applications will develop and become an integrated part of the nation's electrical system, enhancing system reliability, contributing to the reduction of power plant emissions, and lowering system costs.

FIGURE 2Q PEAK VS. NON-PEAK CHARGING



2.5 Consumer Acceptance



Almost a decade since their introduction, penetration rates for gasoline-electric hybrid vehicles are still less than 3 percent of vehicles on the road. More technologically advanced grid-enabled vehicles will need to overcome a number of consumer hurdles in order to reach much higher penetration rates.

New innovations have often required many years to become widely adopted in the marketplace, and hybridization has thus far been no exception. Despite the introduction of the first mass-produced hybrid vehicle, the Toyota Prius, into the U.S. market in 2000,⁴⁰ sales of gasoline-electric hybrids accounted for only 2.8 percent of new light-duty vehicle sales in 2008⁴¹ and less than 1 percent of the total U.S. LDV stock.⁴² PHEVs and EVs have yet to make any noticeable impact, with higher volumes not expected until later in 2010.

Experts on innovation highlight five key characteristics that are vital to the diffusion of any new technology. They are:

1. Advantage over the incumbent
2. Compatibility with the needs of potential adopters
3. Complexity
4. Trialability; and
5. Observability of the benefits to current non-adopters.⁴³

The diffusion of hybrid vehicle technology has so far been hampered by aspects of all of these characteristics. In some cases, there are genuine weaknesses to current technology; in others, they are merely perceived. HEVs and GEVs, for example, actually require less maintenance than internal combustion engine

vehicles,⁴⁴ yet surveys have highlighted higher maintenance costs as one of the single greatest concerns among consumers considering the purchase of a hybrid-electric vehicle.⁴⁵

Much recent study and analysis has gone into uncovering the reasons why consumers purchase HEVs. Among early adopters, the primary reasons for considering the purchase of a hybrid include lower fuel costs and better fuel economy, fewer emissions, and reducing U.S. dependence on foreign oil.⁴⁶ In fact, even those who were not considering purchasing HEVs believe these features to be major benefits of the technology.

There are initial indications that consumer attitudes towards PHEVs are positive as well. A recent survey revealed that 48 percent of prospective U.S. consumers would be “extremely” or “very” interested in purchasing a PHEV with a single-charge, 40 mile range. Of those interested, almost half said that they would be willing to pay 5 to 10 percent more than a traditional IC engine vehicle.⁴⁷ Of course, some of the major societal benefits (or positive externalities) are not always ‘felt’ directly by individual consumers, giving them less incentive to switch to GEVs. Largely leaving aside consumer marketing with respect to issues of environmental and national security benefits, the value of the other positive features of GEV adoption must be more adequately communicated to consumers in a way that they understand.

40 “A Decade After First Prius, Toyota’s Hybrid Sales Pass 1M,” USA Today (June 7, 2008).

41 AEO 2009, Supplement Tables, “Light-Duty Vehicle Sales by Technology Type,” (Table 57) (2009).

42 AEO 2009, Supplement Tables, “Light-Duty Vehicle Sales by Technology Type,” and “Light-Duty Vehicle Stock by Technology Type” (Tables 57 & 58) (2009).

43 Everett M. Rogers, “Diffusion of Innovations,” at 15 (Free Press, 2003).

44 Electric Vehicles (EVs), available at www.fueleconomy.gov/Feg/evtech.shtml, last accessed August 31, 2009.

45 Mike Omotoso, J. D. Power and Associates, “Consumer Attitudes Towards Alternative Powertrains,” Presentation Slide 5 (November 2008).

46 Id. at Slide 4.

47 “U.S. Consumers Interested in Plug-Ins,” Project Green Leaf.

2.5.1 Identifying the Pitfalls of GEV Acceptance

As with any new technology, expanding consumer adoption alongside the incumbent is a critical and difficult challenge. Investment payback and vehicle range are particularly important issues for GEV consumers.

RETURN ON INVESTMENT

Today, due in large part to the cost of batteries, a significant price premium exists on both PHEVs and EVs. For consumers, grid-enabled vehicles hold out the promise of a lower total cost of ownership compared to IC engine vehicles. That is, sharply reduced fuel and maintenance costs eventually payback the GEV battery premium over the life of the vehicle. Current battery prices, however, make the value proposition somewhat tenuous. Even after accounting for the maximum federal tax credit of \$7,500, the payback period today would be roughly eight years for an EV and five years for a PHEV. Without federal tax incentives, the payback period for today's GEVs is beyond the life of the vehicle—approximately 12 years for an EV and 10 years for a PHEV.⁴⁸ Of course, innovative business models and some companies' lower production costs will have an impact on the length of the payback.

But from an industry-wide perspective, the costs for pure EVs make the value proposition somewhat unclear for consumers.

For a PHEV, incorporating the tax credit makes the value proposition somewhat more obvious. And yet, despite the fact that a payback might be fully attainable over the useful life of the vehicle, research suggests that buyers expect product efficiency improvements to pay for themselves in the first three years or less.⁴⁹ Moreover, other studies have shown that buyers rarely estimate the present value of fuel savings as

part of a decision to purchase a new vehicle.⁵⁰ Thus, first adopters are typically over-valuing the expected benefits of these vehicles (or more likely deriving utility from other vehicle features and uses that offset these losses).

Particularly in the context of consumer acceptance, these issues highlight the potential importance of alternative methods of battery financing. Long payback periods assume the continuation of the traditional ownership model whereby the consumer buys the vehicle and all its components from a dealer or manufacturer. However, alternative models certainly exist, and a number of GEV market participants are currently focused on deploying approaches like battery leasing to the nascent GEV market in order to address consumer acceptance issues based on the return-on-investment challenge.

Better Place, mentioned earlier, has proposed a network operator model wherein the company would assume the cost and risk of battery ownership. Consumers would purchase the vehicle, minus the cost of the battery, and essentially pay a subscription fee based on mileage. By subtracting the cost of the battery from a pure electric vehicle, the value proposition becomes compelling for nearly all consumers. How such a network operator would interface with automotive OEMs remains an important question, as does the degree of standardization required across the vehicle and supporting infrastructure.

Finally, an additional component to the consumer's value proposition relates to the cost of home recharging equipment. One recent survey suggested that 79 percent of consumers would be interested in investing in a Level II outlet for their home. Their willingness to pay, however, was found to be out of line

48 PRTM Analysis.

49 M. Kubrik, National Renewable Energy Laboratory, "Consumer Views on Transportation and Energy," at 18 (Table 4.2.1) (Third Ed. 2006).

50 Greene, David L., et al., ORNL/National Transportation Research Center, "Fuel Economy: The Case for Market Failure," (2007).



A couple reviewing finances and paying bills.

with industry expectations.⁵¹ A 2008 study at the Idaho National Laboratory found that Level I charging in a house or apartment would range from \$833 to \$878 per charger, and Level II chargers would cost between \$1,520 and \$2,146.⁵² Modeling estimates conducted for this Roadmap suggest that once installation is occurring at scale, stable costs for home recharging devices will decline substantially.

PERSONAL AND SOCIETAL BENEFITS

A wells-to-wheels analysis of greenhouse gas emissions by the Natural Resources Defense Council (NRDC) has shown significant, measurable benefits exist if PHEVs begin to displace IC engine vehicles in the U.S. LDV fleet. For their reference case, NRDC estimates that by 2050, annual greenhouse gas emissions will be reduced by 163 million metric tons. Under higher fleet penetration and lower emissions scenarios, they predict the reduction could be almost four times as large.⁵³ These are measurable benefits to society, but they are essentially impossible to incorporate into a purchase decision for a consumer buying a vehicle today.

Unsurprisingly, while most consumers may recognize that these benefits exist, they do not value

them highly when making a vehicle purchase. The final decision is based on the consumer's perceived advantages or disadvantages. This is not to say that buyers are ignorant. Far from it; the problem appears to be that no one as yet has successfully measured and monetized the externalities associated with GHGs. While mass media is useful for increasing awareness and initial knowledge of GEVs, most people depend mainly on the subjective evaluation provided by other consumers who have already purchased (or not purchased) a GEV.⁵⁴

In surveys, consumers considering a PHEV purchase offer decreasing U.S. dependence on foreign oil (62 percent), lower emissions (53 percent) and environmental benefits (70 percent) as key motivating factors.⁵⁵ Not one of these gives a noticeable or tangible benefit to the buyer. Even better fuel economy—at 90 percent, the most popular response—fails in practice as a valid reason for buying GEVs because at current prices the fuel savings are insufficient over the average lifespan of the vehicle to cover the increased level of investment.⁵⁶ These more abstract features have been enough to attract only the most willing consumers. This helps explain why the penetration rate of gasoline-electric hybrid vehicles currently available in the market have shown very slow growth since their introduction a decade ago. Of total new car sales, HEVs made up 1.6 percent in 2006, 2.3 percent in 2007 and 2.8 percent in 2008.⁵⁷

51 "48 Percent of Consumers Interested in Purchasing a Plug-In Hybrid vehicle, According to New Survey from Pike Research," Reuters (September 8, 2009).

52 DOE, Vehicle Technologies Program, "Plug-in Hybrid Electric Vehicle Charging Infrastructure Review," (November 2008).

53 Electric Power Research Institute (EPRI) & Natural Resources Defense Council, "Environmental Assessment of Plug-In Hybrid Electric Vehicles—Volume 1: Nationwide Greenhouse Gas Emissions," at 2 (2007).

54 Rogers, supra note 4, at 18.

55 Omotoso, supra note 6, at slide 4.

56 Tax incentives may, however, alter this payback calculation.

57 AEO 2009, Supplemental Tables, "Electric-Gasoline Hybrid Sales 'Divided by' Total Sales," (Table 57) (2009).

Battery financing models could drive down upfront battery costs for consumers.

2.5.2 Consumer Preferences for Vehicle Utility

Divergence from the traditional model of automobile ownership and established consumer preferences for vehicle range, refueling, characteristics and performance have the capacity to affect the rate of GEV penetration.

VEHICLE BASE RANGE

The Department of Energy estimates that most EVs will travel between 100 and 200 miles before recharging.⁵⁸ Today, the numbers being presented by automakers suggest that the earliest models to reach the market may be near the lower end of that range. For example, the Nissan LEAF is rated to travel 100 miles on a full charge,⁵⁹ and the Ford Focus BEV will only achieve 75 miles.⁶⁰ In contrast, some conventional IC engine vehicles can reach 500 miles or more on a single tank of gasoline. While these numbers are far apart, a look at historic vehicle usage patterns suggests that the difference is somewhat immaterial for the typical driver. Very few trips as a proportion of the total are beyond the limits of even today's electric vehicles, let alone those being developed for delivery in coming years.

Today, there are well over 150,000 gasoline stations in the United States, each with multiple pumps, and fewer than 1,000 electric charge points.

As shown in Figures 2R and 2S, 57 percent of trips are shorter than six miles and just 9.8 percent are in excess of 30 miles.⁶¹ In addition, more than 90 percent of driving commutes, which make up almost one-quarter of all trips, are less than 30 miles.⁶² Nationwide,

the average daily travel per driver was 32.7 miles in 2001, grew just under 2 percent since 1995,⁶³ and was considerably shorter than the electric vehicle ranges that we are seeing proposed by manufacturers today. Additionally, in cities and suburban areas where it is anticipated that demand for PHEV and EV technologies will develop most rapidly, average daily travel distances per driver are up to 25 percent shorter than in rural areas. Even in rural areas, however, the average trip is approximately 40 miles, well within the range of today's GEVs.⁶⁴

Still, range anxiety on the part of consumers remains a substantial challenge for GEV adoption. People are simply afraid that in the event of an emergency, their vehicle will be incapable of travelling the long distances required, or that they will be unable to get the necessary recharge along the way. Despite the fact that data on consumer habits shows that drivers only rarely travel very long distances, when asked their opinions, they express unease over range.

Since the 1980s, the average vehicle trip length has risen steadily; in 2001, it reached 9.87 miles.⁶⁵ Over the same time period, the number of trips taken per household has grown by 46 percent, to around six trips every day.⁶⁶ In fact, the number of daily vehicle trips has been in excess of three since 1990.⁶⁷ Some driver concern will almost certainly center on whether the single overnight recharge will provide their vehicle with sufficient energy to go to work, out to dinner and to the supermarket all in the same day. This concern will be exacerbated if opportunities to recharge during the day are limited, but can be alleviated by the deployment of Level II EVSEs and Level III fast chargers around a community.

58 "Electric Vehicles (EVs)," Fueleconomy.gov, available at www.fueleconomy.gov/feg/evtech.shtml, last accessed on October 22, 2009.
 59 "Nissan Unveils 'Leaf'—The World's First Electric Car Designed for Affordability and Real-World Requirements," Nissan Press Release, August 2, 2009.
 60 Ford Motor Company, "Ford Focus BEV Prototype - E-Mobility Without Compromise in Size," September 15, 2009.
 61 S. Davis, S. Diegel & R. Boundy, DOE, Office of Energy Efficiency and Renewable Energy, "Transportation Energy Data Book 2008," at 8-15 (Figure 8.3).
 62 Id.

63 Id., at 8-17 (Table 8.12).
 64 Id., at 8-17 (Figure 8.5).
 65 Id., at 8-7 (Table 8.5).
 66 Id., at 8-8 (Table 8.6).
 67 Id., at 8-17.

FIGURE 2R SHARE OF VEHICLE TRIPS BY TRIP DISTANCE

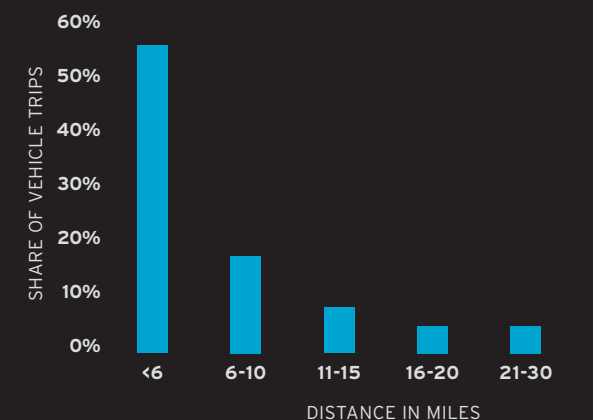


FIGURE 2S SHARE OF VEHICLE TRIPS TO WORK BY TRIP DISTANCE

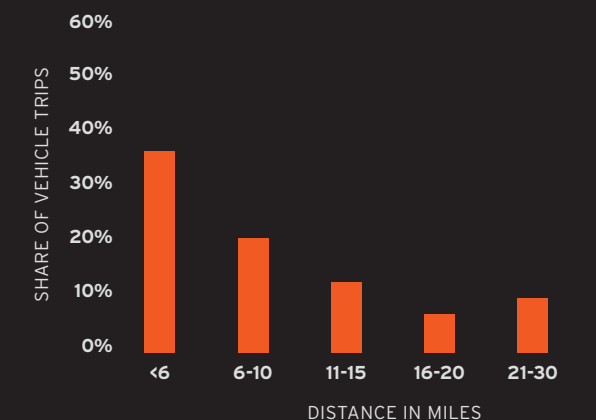


FIGURE 2T AVERAGE DAILY MILES DRIVEN (U.S.)

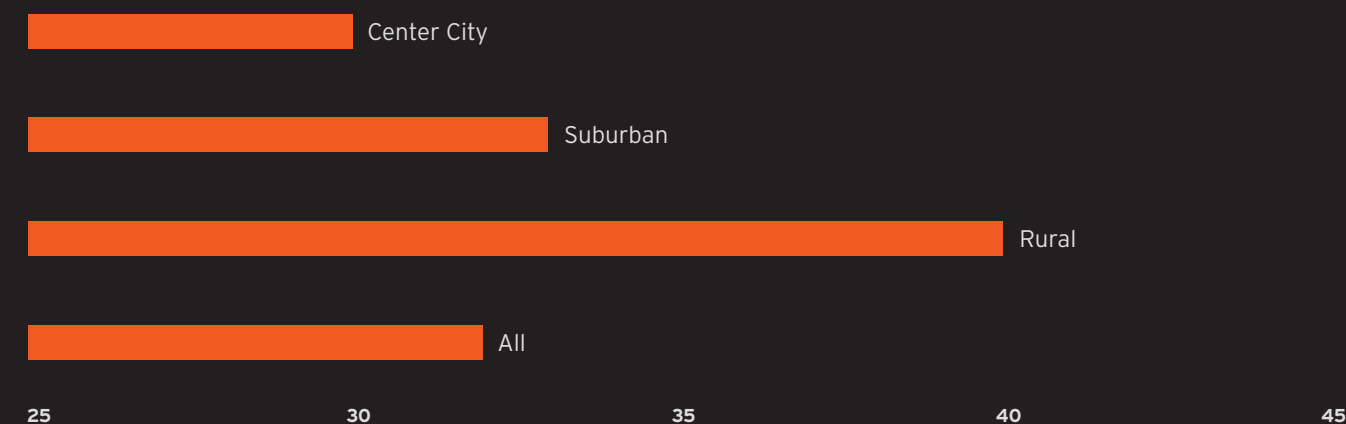
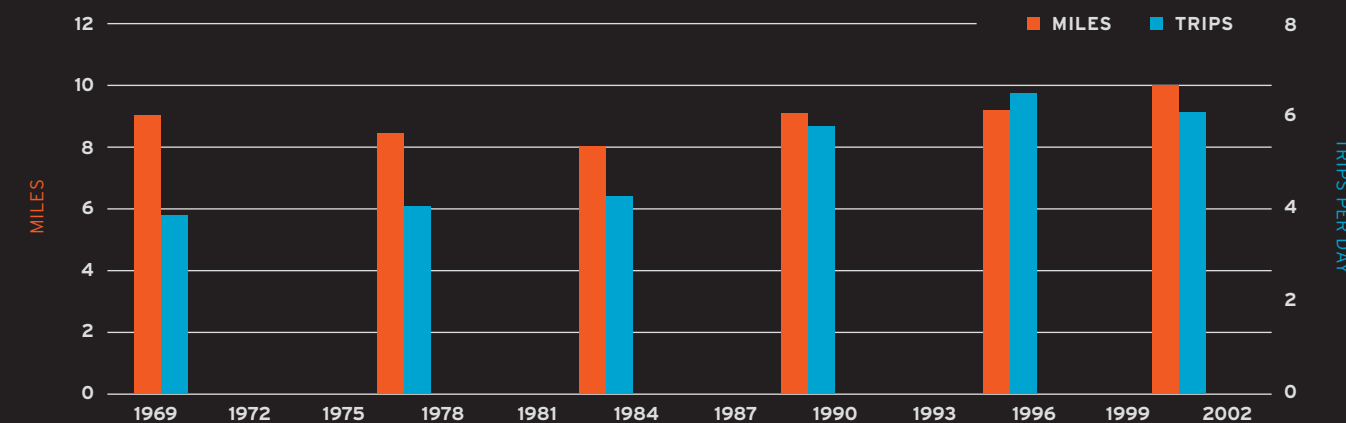


FIGURE 2U AVERAGE NUMBER OF HOUSEHOLD TRIPS PER DAY AND AVERAGE VEHICLE TRIP LENGTH



Source: DOE, EERE, Transportation Energy Data Book (2009)



One of the two billion long distance trips made each year by personal use vehicles, average 400 miles each.

Driver concerns over trip length bring us to a final issue: the great American road trip, and other long-distance journeys. The United States is a vast country. The distance from New York to San Francisco is more than 2,900 miles, Seattle to Miami is almost 3,500 miles, and a drive across Texas alone tops 800 miles. While trips like these are obviously rare in an age of air travel, every year more than 2 billion long-distance trips are made by personal use vehicles—representing more than 90 percent of long-distance trips.⁶⁸ With such trips averaging 400 miles, clearly refueling is an important issue for any vehicle technology. Today, there are well over 150,000 gasoline stations in the

United States, each with multiple pumps, and fewer than 1,000 electric charge points.⁶⁹ But even if a recharging network were ubiquitous, fully charging an electric vehicle at a Level II EVSE takes far longer than filling a tank with gasoline. Addressing this challenge will require the deployment of Level III fast chargers, which should be able to charge a vehicle in a matter of minutes rather than hours, or battery swapping networks.

The development of PHEVs and extended range electric vehicles (E-REVs) attempts to address these concerns by providing the consumer with an operational model less removed from the norm. In addition to the presence of an electric motor, these vehicles continue to make gasoline-powered driving available, thereby extending range (to as much as 300 miles in the case of the Volt, for example). As mentioned earlier, we anticipate that as battery technology becomes more advanced, manufacturers and drivers will be able to transition away from PHEVs and E-REVs toward EVs.

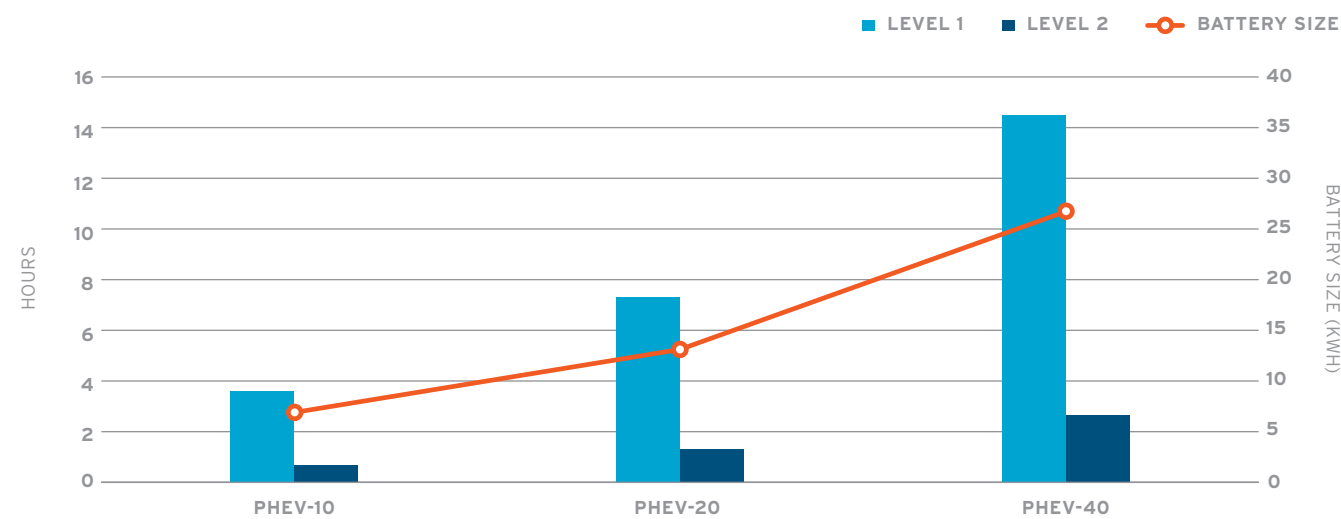
OPERATIONAL CONSISTENCY

After more than a century of automobile development, refinement and use in the United States, vehicle ownership and operational norms are well established. To many potential consumers, the behavioral transformation required in the switch to EVs must seem

69 DOE, Office of Energy Efficiency and Renewable Energy, Alternative Fuels and Advanced Vehicles Data Center, “Electric Charging Station Locations.”

68 Id., at 8-27 (Table 8.21).

FIGURE 2V HOME CHARGING TIMES FOR MID-SIZE PHEVS



Source: Idaho National Laboratory



daunting. This is completely understandable. Not only are vehicle interfaces, refueling processes, and service requirements different, they are also something of a mystery.

Penetration of GEVs and even HEVs is simply so low that many consumers do not know enough about them to seriously consider a purchase.⁷⁰ If GEVs become more widespread, standard financing methods are likely to be used. However, some have suggested a variety of ownership models, including ones in which the battery is not owned by the car buyer. It could be that these models are used simply to aid the widespread introduction of EVs and PHEVs by sharing risk across the parties involved and reducing driver liability. It is unknown if a culture of ownership in the United States may make business models like these less palatable to new car buyers. Until one or more business models are established as viable, consumer reluctance will continue.

Furthermore, new car sales are estimated to top out at just over 10 million units in 2009. Used car sales, in contrast, are expected to reach 40 million.⁷¹ One study estimated that the typical American owns a car for only six years.⁷² Another study estimates that vehicles are kept for up to four years across all income levels, while drivers above the 30th income percen-

70 Omotoso, supra note 6, at Slide 4.

71 Bob Gritzinger, “Used Car Sales Rise as Buyers Shun New Cars,” MSN.com.

72 J. Romm & A. Frank, “Hybrid Vehicles Gain Traction,” Scientific American, at 72-79 (April 2006).

tile are likely to change cars after two years.⁷³ But no resale market currently exists for GEVs. The result

GEV features must meet or surpass the features that traditional IC engine vehicles provide if they are to succeed in the marketplace.

is another disincentive—for both secondary buyers (lower income) and primary buyers and first sellers (higher income)—to adoption.

Finally, the actual process of refueling is long ingrained in drivers’ behavioral patterns. With pay-at-pump options today, IC engine vehicle owners can refuel and pay in just a few minutes. The greater the shift away from this model, the more complex it will be for the consumer and the slower the rate of GEV adoption. The amount of time it takes to recharge a vehicle battery varies. It depends in large part on the battery’s state of charge and how much energy the battery holds. In mid-2003, the California EPA Air Resources Board (CARB) noted that it took two to five hours to charge most EVs that are 1/4 to 3/4 full, and from four to eight hours to fully charge an EV from empty.⁷⁴ By comparison, as depicted in Figure 2V, a

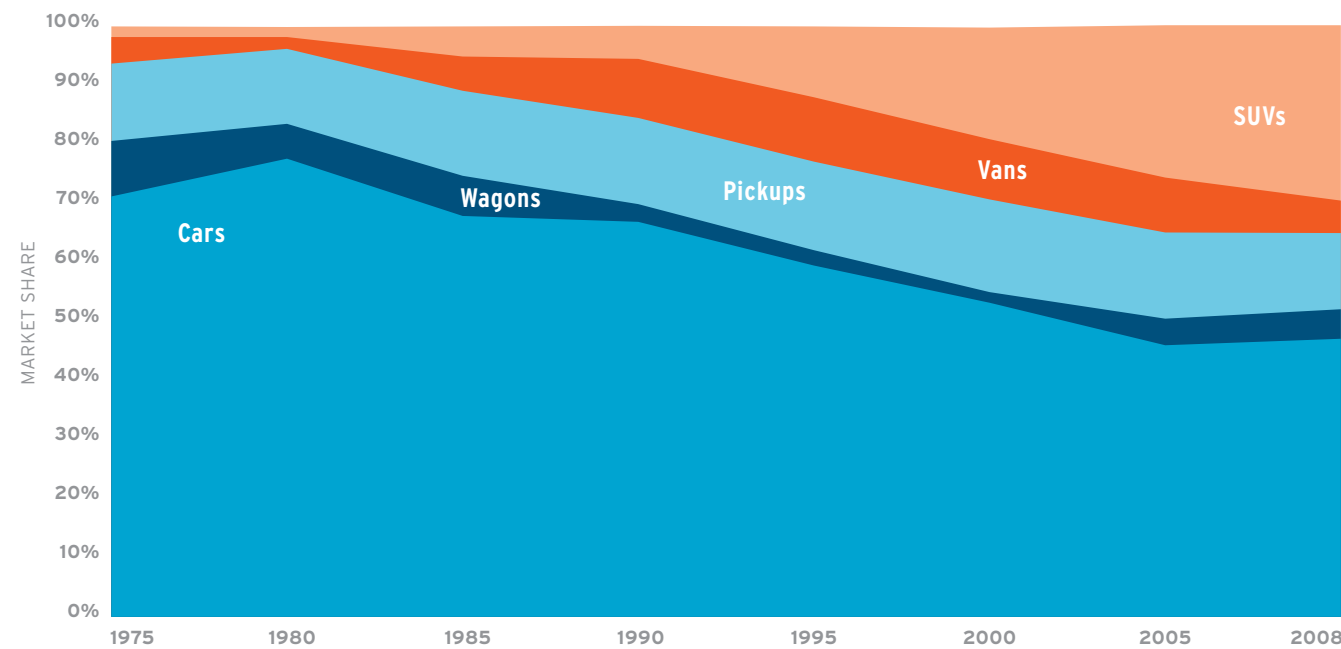
73 A. Yurko, University of Texas at Austin, “From Consumer Incomes to Car Ages: How the Distribution of Income Affects the Distribution of Vehicle Vintages,” (Working Paper) (2008).

74 California Air Resources Board, “Fact Sheet: Battery Electric Vehicles.”



The 2007-2009 recession was characterized by a sharp reduction in consumer spending. One of the most adversely affected areas of the economy has been the automobile industry.

FIGURE 2W U.S. LIGHT-DUTY VEHICLE SALES BY TYPE



Source: EPA

2008 study by the Idaho National Laboratory found that the charge times for mid-size PHEV-10s, PHEV-20s and PHEV-40s were between 3.6 and 14.5 hours for Level I charging, and 0.67 and 2.67 hours for Level II charging.⁷⁵ More recently, Tesla Motors has developed a home charging system for its EV Roadster with a charging rate of 56 miles range per hour; this system can fully recharge the vehicle from empty in less than four hours.⁷⁶

VEHICLE PERFORMANCE

Between 1978 and 1985, fuel economy standards for passenger cars rose from 18.0 miles per gallon to 27.5 miles per gallon.⁷⁷ In the years that followed, and despite technological advances that made further improvements in fuel economy increasingly possible, they remained almost unaltered until 2007. Moreover, higher profit margins and weaker CAFE standards for pick-up trucks and SUVs encouraged OEMs to shift focus toward larger vehicles that get

fewer miles per gallon than those they functionally displaced.

As a result, the mix of new vehicles sold has changed dramatically over the past 20 years. In 1983, SUVs accounted for just 2.9 percent of new LDV sales. In 2007, they accounted for 27.0 percent of LDV sales, representing the largest segment of the LDV market.⁷⁸ This trend towards larger and more powerful vehicles may have also contributed to shifting consumer attitudes towards smaller cars. One recent study carried out in California concluded that a negative social stigma against more fuel-efficient vehicles exists. Automobiles with good fuel economy were often associated with being “cheap,” “light,” and “small.”⁷⁹ In fact, here again the issue of perception versus reality emerges. Because electric motors deliver torque to the wheels at much higher rates than conventional drivetrains, the driving experience for GEVs is likely to be at least as good as, if not better than, that of an IC engine vehicle.

Variety of models is another factor in eventual consumer adoption of GEVs. Consumers will ultimately demand vehicles of all shapes and sizes. In 2009, there were just 28 HEVs commercially available

75 DOE Vehicle Technologies Program - Advanced Vehicle Testing Activity, “Plug-in Hybrid Electric Vehicle Charging Infrastructure Review.”

76 Tesla Motors, “Charging Solutions: Which One is Right for You.”

77 National Research Council, “Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards,” at 1 (2002).

78 DOE, EIA, “Issues in Focus: Fuel Economy of the Light-Duty Fleet,” (2005).

79 “Car Buyers and Fuel Economy?” Energy Policy, Vol. 35, at 1213-1223 (2007).



Customers in Miami, FL fill their vehicles and extra fuel tanks with gas as they prepare for the approaching Tropical Storm Ernesto.

in the United States.⁸⁰ No EVs or PHEVs are yet available to the mass market. Clearly if a consumer is looking for an SUV in particular, he or she has many more options if purchasing a traditional IC engine vehicle.⁸¹ Some car manufacturers have recognized this particular consumer need, and a number of larger vehicles are now available on the HEV platform, including the Ford Escape Hybrid, the Chevrolet Silverado 15 Hybrid, the Cadillac Escalade Hybrid and the Toyota Highlander Hybrid.⁸²

Through decades catering to many types of buyers, car companies as a whole now provide suitable vehicles for essentially anyone who requires one, and in many instances the buyer has a variety of options to choose from, each competing mostly over branding, servicing contracts, quality perception, add-ons and other luxuries. Features like noise output, style and appearance, including vehicle communications interfaces, give the consumer utility. In fact, back in the late 1980s and early 1990s, when researchers quantified things such as comfort, freedom,

flexibility and mobility into monetary terms and then surveyed drivers about their preferences, they found that drivers believed electric vehicles had a disutility of between \$10,000 and \$16,250.⁸³ GEV features must meet or surpass the features that traditional IC engine vehicles provide if they are succeed in the marketplace.

80 DOE, EERE, “2009 Hybrid Vehicles.”

81 United States Department of Transportation, National Highway Traffic Safety Administration, Automotive Fuel Economy Program, “Annual Update Calendar Year 2003,” (2004).

82 DOE, EERE, “2009 Hybrid Vehicles.”

83 Sovacool, B. and Hirsh, R, “Beyond Batteries: An Examination of the Benefits and Barriers to Plug-In Hybrid Electric Vehicles (PHEVs) and a Vehicle-to-Grid (V2G) Transition,” Energy Policy Vol. 37 at 1095-1103 (2009).

POLICY RECOMMENDATIONS

Batteries & Vehicles



Establish tax credits for installing automotive grade batteries in stationary applications to help drive scale

Discussion: To promote the manufacture of automotive grade lithium-ion batteries, Congress should establish a tax credit for the purchase of automotive grade batteries for stationary uses. Lithium-ion batteries are technologically suitable for use in stationary applications, including residential backup power and power storage for intermittent electricity sources like wind and solar power. However, because of the extremely high levels of durability and production quality required for automotive use, automotive grade batteries are likely to be too expensive for stationary uses.

Still, the lack of scale in vehicle battery production is a primary impediment to driving down costs throughout the industry, and incremental demand from the electric power sector and other stationary applications could help expand battery supply chains across a number of inputs. By expanding the existing vehicle tax credit to include incremental kWh of battery capacity installed, Congress would significantly expand the market for automotive grade lithium-ion batteries and help develop the scale of production needed to reduce the cost of GEVs.

Establish loan guarantees for retooling automotive assembly lines

Discussion: In order to reach the goals put forward in this report, GEVs will need to become an increasingly significant portion of new U.S. vehicle sales over the next 10 years. Even as battery technology advances, infrastructure is deployed, and consumer attitudes shift, the demands on automotive original equipment manufacturers (OEMs) to retool facilities will be daunting.

Currently, the cost to retool an automotive assembly line with an annual capacity of 100,000 vehicles is estimated at approximately \$500,000,000. These are non-trivial costs, especially in a time of economic instability. In order to enable the industry to reach the scale required to deploy electric vehicles in large numbers, additional federal assistance for retooling and other capital outlays will be necessary. Any automotive OEM with U.S. facilities should be eligible.

Offering loan guarantees is the most cost effective way to leverage federal dollars. Congress should provide the Department of Energy with \$10 billion to support loans up to \$100 billion for automotive retooling to manufacture GEVs, including electric drivetrain components and final assembly. This amount is a sufficient volume of loans to support the eventual development of capacity to manufacture approximately 13 million GEVs annually by 2020.

POLICY RECOMMENDATIONS

Charging Infrastructure



Modify building codes to promote GEV adoption

Discussion: Department of Transportation data indicates that the average vehicle spends as much as 75 percent of its time parked at home, including all overnight hours. For that reason, there is near universal agreement that each GEV will need a charging device at home for overnight charging. In many instances, homeowners do not have a 220 volt outlet in their garage or accessible to their driveways; a professional electrician would be required to install a 220 volt line and recharging equipment. Doing so could be costly, depending on the difficulty of running a wire from a home's electrical panel to the garage.

To simplify this process, homebuilders could place lines in new garages and carports when homes are first built (or perhaps during certain renovations), significantly lowering the cost of adding EVSE later. Building codes should be modified to require that newly constructed homes and multi-family units have 220 volt outlets installed in garages or, at a minimum, have conduits installed that will facilitate the later installation of 220 volt lines.

Generally speaking, building codes are developed by independent standards organizations and implemented by states or cities. Congress has, however, required states and local governments to implement certain provisions into their building codes to obtain eligibility for certain government programs. In this instance, Congress should limit the applicability of tax credits for GEVs to cars registered in states (or localities) that have incorporated the wiring requirements discussed above into their building codes. Such a requirement will facilitate the eventual deployment of GEVs by lowering the cost of installing GEV charging infrastructure.

POLICY RECOMMENDATIONS

Electric Power Sector Interface



Promote the inclusion of GEV-related investment in the utility rate base

Discussion: As a result of their experience, utilities may be skittish about significant investments to support the deployment of GEVs which may or may not ever be deployed. Utilities may be concerned that if they make such investments and GEVs are not deployed in sufficient numbers, utility regulators may later determine that the investments were not prudent and disallow those costs.

Some will oppose a federal requirement regarding what is traditionally an area of state regulation. If, however, the nation is to treat oil dependence as a national problem, its resolution cannot be left in the hands of state utility regulators. In the event that state regulators do not move to allow incorporation of the technology needed to support GEV deployment in utilities' rate bases, Congress, should establish a minimum level of utility investment in GEV-related technology upgrades that state regulators must approve, and that once approved cannot later be disallowed on the grounds that the investments were imprudent.

Adjust utility rate structures to facilitate GEV deployment

Discussion: Where necessary, public policy and regulations should be adjusted to support development of separate rate structures and billing options for service providers to develop new business models that maximize benefits for GEV owners. Utilities will need to establish time-of-day pricing for power used to charge vehicles to encourage off-peak charging or create other innovative tariffs for the sale of power to charge GEVs to help manage load. State utility regulators should encourage utilities to experiment with such rate structures in order to improve utility operations and offer service providers, network operators and consumers a greater value.

POLICY RECOMMENDATIONS

Consumer Acceptance



Establish a guaranteed residual value for used large-format automotive batteries

Discussion: The lifecycle characteristics of lithium-ion batteries remain a subject of intense research. However, most current analyses suggest that even as automotive batteries reach the end of their useful life in a GEV, substantial opportunities exist for secondary applications. Enabling consumers to capture the residual value of automotive battery purchases could significantly offset the higher upfront cost of purchasing a grid-enabled vehicle.

Unfortunately, the monetary value of automotive batteries for secondary applications is highly uncertain today. In general, this is because markets simply have not developed any experience with the performance of batteries in these applications. Over time, as the first generation of GEV batteries enters the market, a value will surely be derived. If nothing else, the recycling of battery raw materials alone will generate a notional return on investment for consumers. More likely, battery values will be well in excess of the recycling value as their use in the electric power sector and secondary vehicle markets drive demand. In the meantime, however, markets are likely to undervalue lithium-ion batteries due to their inability to assess the risk of an unknown technology. This problem will be particularly challenging for promoters of battery leasing, because understanding the residual value of the leased item is critical in establishing the cost of a lease.

Therefore, Congress should authorize the DOE to establish a program to guarantee residual value for large-format automotive batteries. Compared to the uncertainty of battery research and development, establishing a minimum residual value would effectively buy down the cost of batteries immediately. Moreover, while the ultimate cost of such a program is dependent on the actual residual value of batteries, it holds out the possibility of not imposing any meaningful costs on the government, assuming the actual residual value is higher than the minimum guarantee.

Review existing regulations on vehicle warranties

Discussion: Consumers and policymakers may need to consider a new approach to vehicle warranties as they relate to grid-enabled vehicles. Business models like battery financing can help de-risk the value proposition of GEVs for consumers, but they also raise important questions about the ultimate responsibility for guaranteeing performance over the life of the battery.

Current regulations that require manufacturers to warranty components for the expected life of the vehicle may hinder the earliest efforts to develop cost-effective batteries by forcing manufacturers to over-specify battery capacity. Further, the anticipated acceleration of technological innovations in the battery industry could make each iteration of batteries obsolete within several years. Traditional warranty rules could slow the pace of technological diffusion.

The National Academies should review existing regulations on vehicle warranties and make policy recommendations with regard to GEVs.

PART THREE

Analysis of the Goal



3.1 ASSESSING THE TARGET



3.2 TOTAL COST OF OWNERSHIP

The High Five Freeway Interchange, Dallas, TX.
Before grid-enabled vehicles fill America's highways, they will need to present consumers with a compelling value proposition.

ABSTRACT

Analysis of the Goal

Part One of this Roadmap set a national goal for electrification. Specifically, by 2040, 75 percent of the vehicle miles traveled (VMT) in the United States should be electric miles. Part Two of the report outlined the challenges facing electrification market participants and also noted important opportunities for overcoming those challenges. Part Three presents the results of an analysis of the goal, including required vehicle adoption rates, scenarios for infrastructure deployment, and impact on the electric power sector. This section concludes with the results of a total cost of ownership analysis for both pure electric vehicles and plug-in hybrid electric vehicles.

3.1 Assessing the Target



A specific and measurable target is a vital precursor to a successful implementation strategy. By setting and committing to a goal of electrifying 75 percent of the vehicle miles traveled in the light-duty fleet by 2040, the government will put the United States in a strong position to significantly reduce its dependence on oil.

3.1.1 VEHICLE MILES TRAVELED

Expressing a national goal in terms of “electric miles” acknowledges two key issues. First, expressing the goal in terms of market share or sales penetration alone would not necessarily translate directly to an equivalent oil abatement number. That is, reaching the point where 50 percent of all light-duty vehicles were GEVs would not necessarily reduce LDV oil consumption by 50 percent. This is because different population segments account for varying proportions of total miles traveled. Setting an ambitious VMT target clarifies that notion that GEVs will need to be adopted by all

consumer segments, particularly those that account for the highest share of miles traveled.

Expressing the goal in terms of VMT also addresses a technology issue. That is, the transition from a market dominated by IC engine vehicles to one dominated by GEVs will likely incorporate a number of technological solutions within the framework of electric drivetrains. There will surely be an assortment of GEV technologies on the road, including plug-in hybrids, extended range electric vehicles, and pure electric vehicles. From a broad perspective, it makes little difference which technology is dominant at any given time, because each one has the capacity to operate in

FIGURE 3A 2001 NATIONAL HOUSEHOLD SURVEY STATISTICS

WEEKDAY VEHICLE MILES OF TRAVEL PER DAY	PERCENTAGE OF VMT	CUMULATIVE PERCENTAGE
Less than or equal to 5	10	10
Greater than 5 and less than or equal to 10	12	23
Greater than 10 and less than or equal to 20	21	44
Greater than 20 and less than or equal to 30	16	60
Greater than 30 and less than or equal to 40	11	71
Greater than 40 and less than or equal to 50	8	79
Greater than 50 and less than or equal to 60	5	84
Greater than 60	16	100
WEEKEND VEHICLE MILES OF TRAVEL PER DAY	PERCENTAGE OF VMT	CUMULATIVE PERCENTAGE
Less than or equal to 5	22	22
Greater than 5 and less than or equal to 10	21	42
Greater than 10 and less than or equal to 20	27	69
Greater than 20 and less than or equal to 30	7	77
Greater than 30 and less than or equal to 40	6	82
Greater than 40 and less than or equal to 50	4	86
Greater than 50 and less than or equal to 60	6	89
Greater than 60	11	100

Source: David B. Sandalow, "Plug-in Electric Vehicles," (2009)

an all-electric charge depleting mode. An electric mile is simply any mile in which the vehicle is propelled by an electric motor or, for miles traveled in PHEVs or E-REVs, the total miles traveled multiplied by the percent of total power provided by electricity from the grid. Using electric miles as a common measurement, therefore, facilitates the use of a single goal that is applicable over a range of GEVs.

An examination of data regarding VMT also reveals the extent to which existing GEV technology can already meet the needs of most drivers. Figure 3A presents data from the Bureau of Transportation Statistics' 2001 National Household Survey. The data indicates that drivers who travel on average 40 miles per day or less account for 71 percent of total vehicle miles traveled. While PHEVs and E-REVs will effectively have unlimited range (subject to the availability of gasoline) and can inherently meet the needs of any driver, the earliest model GEVs will have the capability to operate primarily on electricity, enabling drivers to obtain the benefits of driving under electric power for most of their miles traveled. EVs with a range of as little as 60 miles could meet the daily needs of drivers who account for 84 percent of total VMT as battery cost and range improve. To the extent that fast charge facilities are deployed, even EVs will have sufficient range and recharging capabilities to meet the needs of almost any driver.

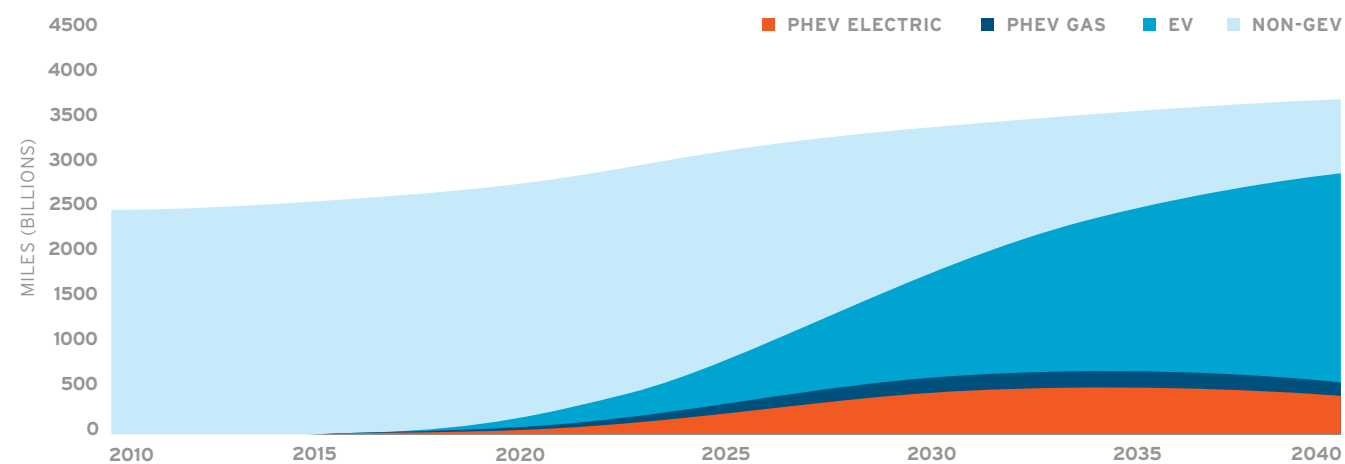
3.1.2 A NOTE ON TECHNOLOGY

As discussed in detail in Part Two, PHEVs and E-REVs utilize both an electric drivetrain and certain components of a traditional internal combustion engine vehicle. At a minimum, E-REVs maintain the use of a fuel tank and a down-sized IC engine as a generator to charge the battery. Some PHEVs will also incorporate additional components of a traditional drivetrain into a gasoline-electric hybrid drivetrain.

This dual system approach is designed to address a specific issue: range anxiety. Because liquid fuel power is available to charge the battery, PHEVs and E-REVs will be able to operate well beyond the charge-depleting mode of the battery, and owners can refill their tanks at any traditional gas station. In other words, PHEVs and E-REVs are not solely dependent on access to public electric vehicle supply equipment to charge their batteries.

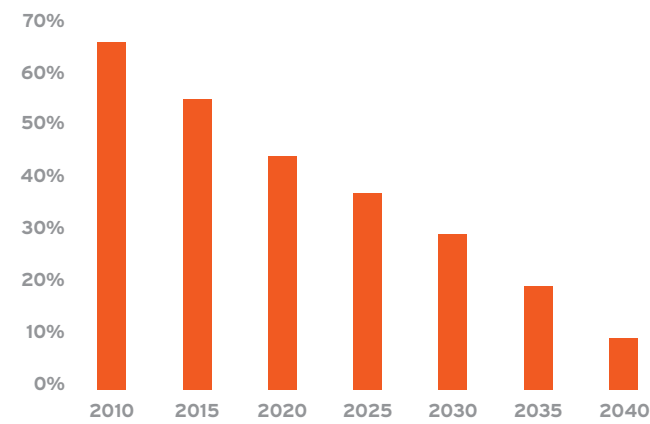
However, the dual system approach is also cost intensive. In essence, expensive components from two different drivetrains are used to manufacture a single hybrid gasoline-electric vehicle. As long as battery prices are high, the hybrid gasoline-electric powertrain system is cost-effective, because EVs require much larger batteries that entail higher upfront costs for consumers. As battery prices fall, however, an inflection point will be reached where pure EVs are not only logistically simpler to produce—because they do not have the added complexity of a gasoline engine married with an electric drive system and the subsequent

FIGURE 3B TARGETED VEHICLE MILES TRAVELED



Source: PRTM Analysis

FIGURE 3C PHEV SHARE OF TOTAL GEV SALES



Source: PRTM Analysis

redundant control systems—but are also less costly than PHEVs or E-REVs.

Moreover, as battery range improves, public electric vehicle supply equipment becomes more commonplace, and Level III chargers are deployed, the range anxiety issue associated with pure EVs will likely dissipate. For these reasons, this analysis assumes that PHEVs will maintain a significant share of total GEV sales early in the adoption cycle, but that EVs gradually replace PHEVs as the dominant platform.

3.1.3 ELECTRIC VEHICLE ADOPTION RATES

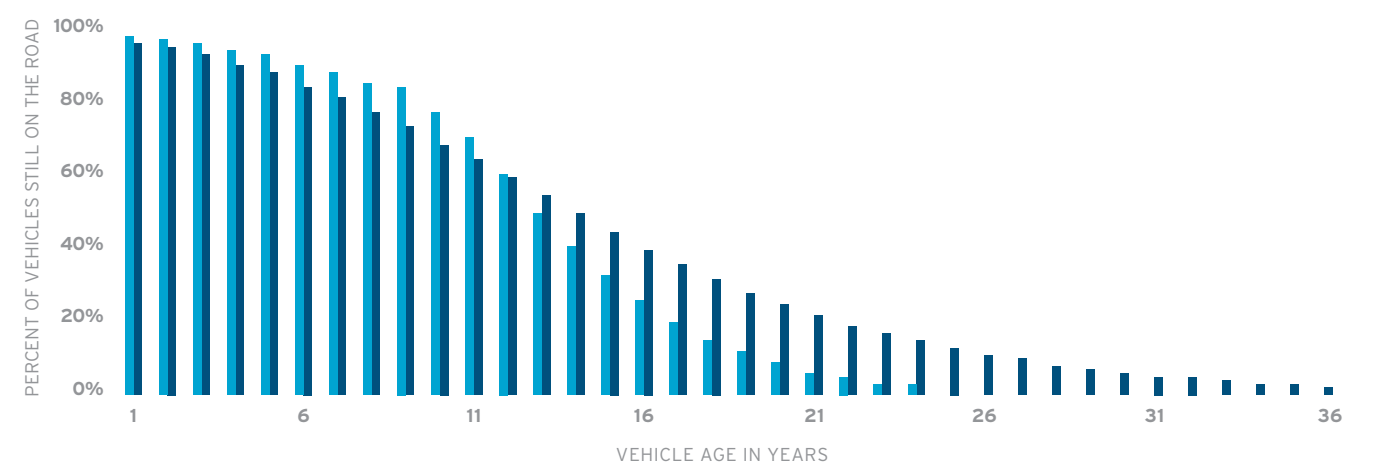
In order to reach the goal of 75 percent electric VMT by 2040, grid-enabled vehicles will need to make

significant inroads into new light-duty vehicle sales between 2010 and 2020 and then expand that share over the following two decades. In part, this is due simply to the massive stock of light-duty vehicles in the United States—in 2008 there were approximately 250 million cars and light trucks on the road. New vehicle sales have fluctuated based on economic conditions, but before the recent recession annual sales were averaging approximately 15 million vehicles.

At the same time, the total number of vehicles on the road has been growing along with the total population. The total number of motor vehicles in the United States increased from 155.8 million in 1980 to 188.8 million in 1990. By 2000, the figure increased to 221.5 million. In other words, new vehicle sales are not necessarily replacing an older vehicle. In fact, available data suggests that cars and light trucks tend to stay on the road for many years. Figure 3D displays the survivability rate for light-duty vehicles by vehicle age. After 15 years, more than 30 percent of cars and 40 percent of light trucks are still on the road. Admittedly, the number of miles traveled tends to decline along with vehicle age. Nonetheless, the extremely long life of light-duty vehicles is an important factor that directly affects the rate at which new technologies can achieve high rates of adoption in the aggregate vehicle fleet.

Based on these factors, this Roadmap has identified two tangible milestones by which the nation can measure progress toward meeting the ultimate VMT goal in 2040:

FIGURE 3D CAR AND LIGHT TRUCK SURVIVABILITY



Source: DOE, National Energy Technology Laboratory

FIGURE 3E REQUIRED SALES PENETRATION

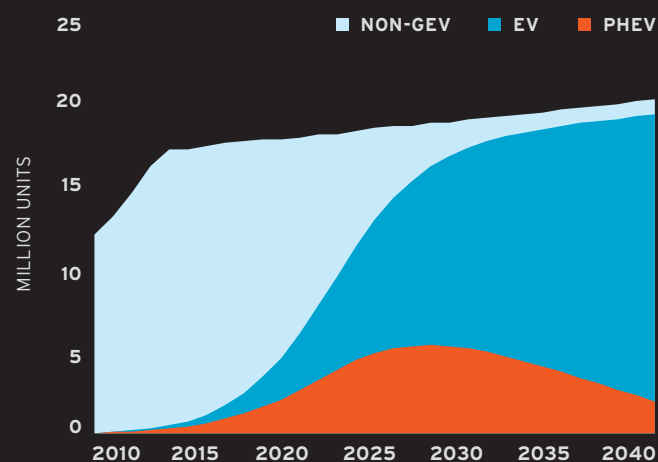


FIGURE 3F REQUIRED FLEET PENETRATION

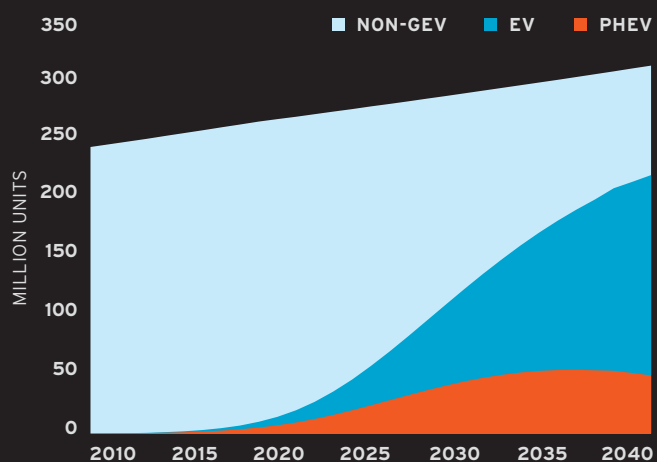


FIGURE 3G EXPECTED LIGHT-DUTY VEHICLE OIL ABATEMENT

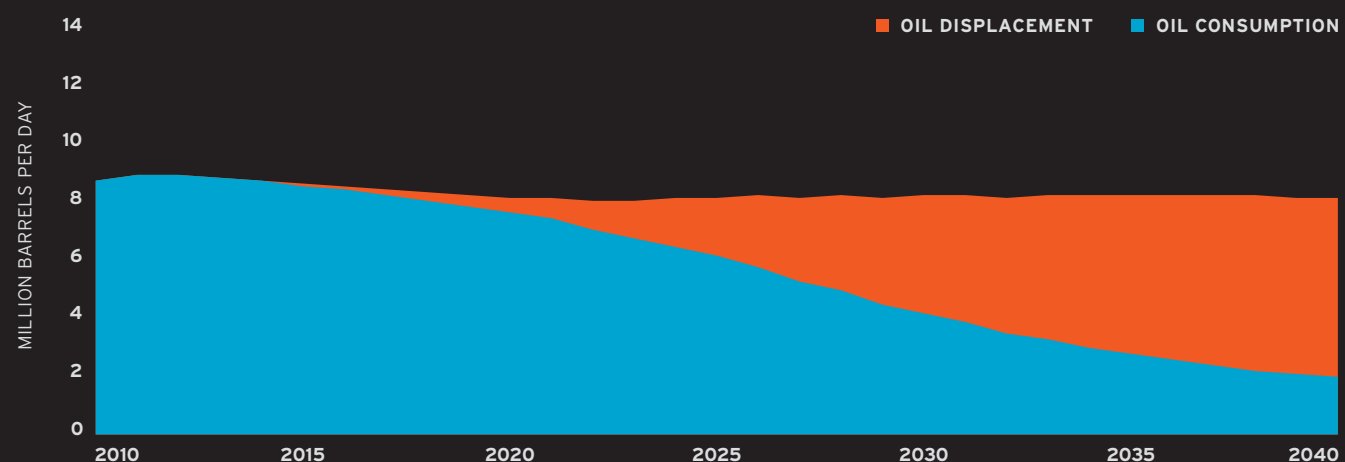


FIGURE 3H PUBLIC CHARGERS NEEDED TO SUPPORT GEV VOLUMES

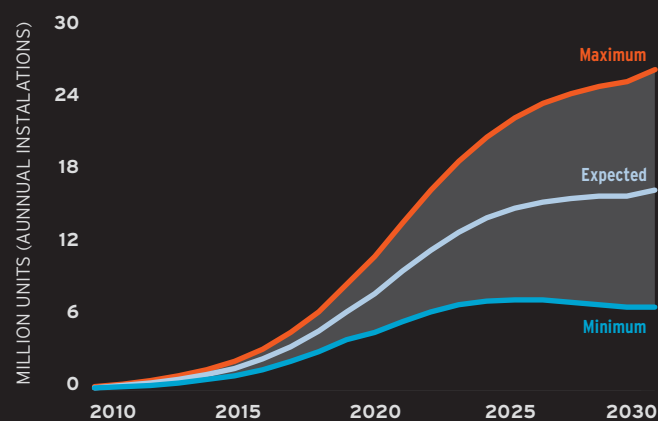
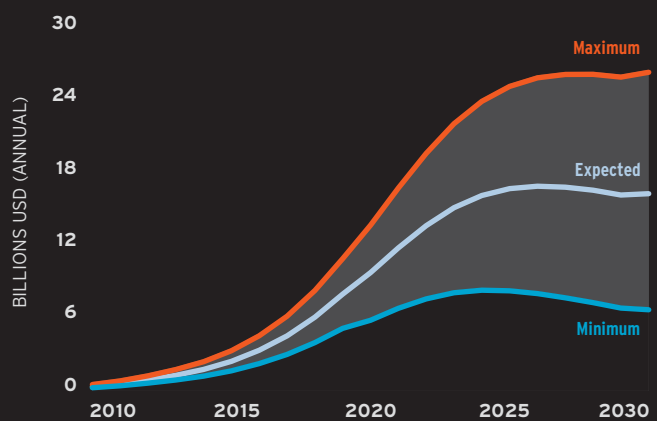


FIGURE 3I COST OF PUBLIC CHARGERS TO SUPPORT GEV VOLUMES



Source: PRTM Analysis



FIGURE 3J RATIO OF PUBLIC CHARGERS TO GEVS

	2010	2020	2030
Expected Public Chargers per Vehicle	2.0	1.5	1.0
Maximum Public Chargers per Vehicle	2.5	2.0	1.5
Minimum Public Chargers per Vehicle	1.5	1.0	0.5

Source: PRTM Analysis

Milestone One

By 2020, at least 25 percent of new vehicle sales are some form of grid-enabled vehicle. (As discussed earlier, it is likely that at this early stage, PHEVs will be the dominant technology.) Reaching this level of sales penetration will require important progress in the years between 2010 and 2020, and appropriate government incentives will be instrumental in catalyzing the market.

The rate of sales penetration envisioned in Milestone One translates into a fleetwide penetration rate of just 5 percent. However, the importance of reaching Milestone One is the trajectory on which it sets the GEV market. That is, only by quickly moving up the adoption curve can GEVs begin to make significant inroads into the broader light-duty vehicle fleet in a reasonable timeframe.

Milestone Two

By 2030, grid-enabled vehicles become the dominant technology for light-duty vehicles. Approximately 90 percent of new vehicle sales are based on an electric drive train, and EVs have overcome PHEVs and E-REVs as the dominant GEV platform. Grid-enabled vehicles are 40 percent of the total number of light-duty vehicles on the road in the United States.

Beyond 2030, as grid-enabled vehicles maintain a dominant share of new vehicle sales, their rate of penetration in the broader fleet increases. By 2040, approximately two-thirds of the U.S. vehicle fleet is some form of GEV.

3.1.4 EXPECTED OIL ABATEMENT

The rates of adoption outlined above translate into significant reductions in oil consumption. By 2030, oil consumption in the light-duty fleet is 4.2 mbd compared to 8.2 mbd in the base (status quo) case. By 2040, light-duty oil consumption falls to just 2.0 mbd, a reduction of 6.0 mbd compared to the base case. Over the cumulative period from 2010 to 2030, electrification of transportation would eliminate more than 29 billion barrels of U.S. oil consumption valued at \$3.7 trillion (\$2007).

3.1.5 ELECTRIC VEHICLE SUPPLY EQUIPMENT

To support the GEV adoption rates commensurate with the goal, substantial investment in charging infrastructure—both public and private—will be required. Essentially all owners of grid-enabled vehicles will

require dedicated access to a charging unit for overnight charging. Moreover, in order to minimize range anxiety, facilitate longer trips, and provide convenience for consumers, some amount of public charging infrastructure will also be required.

As discussed in Part Two of this Roadmap, the exact number of public charging units is unclear. During the early stages of adoption, when range anxiety is highest and familiarity with GEVs is low, it is likely that investment in public charging equipment will need to be more intense. Over the long-term, as consumers gain experience and comfort with vehicle reliability and state-of-charge, deployment of public electric vehicle supply equipment can be more targeted.

For the purposes of this analysis, we have assumed the reference case ratio of public chargers to GEVs presented in Table 3J. This ratio was then applied to the penetration rate of GEVs required to meet the national goal. The annual number of public charger installations is displayed in Figure 3H. The annual cost of those units is presented in Figure 3I. Each of the three cases assumes a standard attrition rate of 10 years.

3.1.6 ELECTRIC POWER SECTOR

The nation can accomplish this aggressive goal without imposing a significant burden on the electric power sector. Because central station power plants and electric motors are much more efficient than internal combustion engines, approximately 124,000 Btu of gasoline (in a car that achieves 24 mpg) can be displaced by approximately 21,000 Btu of electricity (in a car that achieves 4 mpkWh), reducing the nation's overall energy demand. Moreover, as explained earlier in the report, the electric power system is built to meet peak demand and has significant excess capacity during most hours of the year.

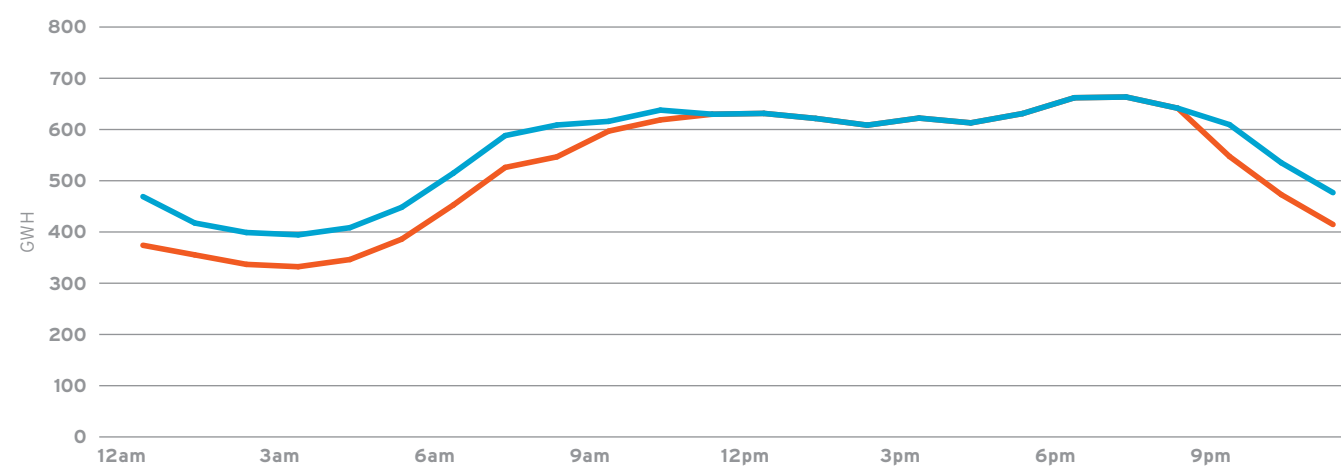
Figure 3K presents the U.S. average load curve associated with the GEV volumes envisioned by this

Roadmap, assuming appropriate technologies and consumer incentives are in place to promote off-peak charging. The primary effect of wide-scale GEV deployment on the power sector is to fill some of the valleys in utility load curves, increasing the overall efficiency of their operations. By managing Level I and II EVSEs to direct vehicle charging largely to off-peak hours, the electric power sector can generate all of the electricity needed to power GEVs without deploying substantial additional power sources or transmission lines.

As demonstrated in Figure 3L, the incremental demand for electricity to support the GEV volumes envisioned in this Roadmap is a relatively small portion of the nation's total demand for electricity.

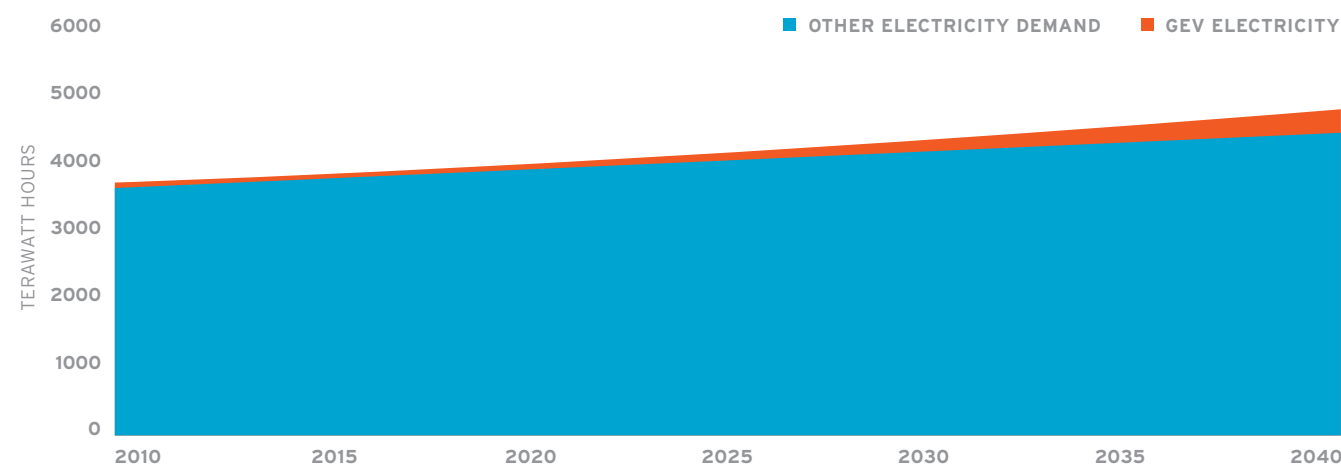
This does not, however, obviate the need for increased deployment of renewable power, nuclear power, and natural gas. As carbon emission constraints are both established and tightened, new sources of low emission or carbon emission free power will have to be built in order to maintain a reliable supply of clean power. Nevertheless, it is clear that we have the ability to generate all of the electricity needed to power our light-duty fleet when operating as GEVs without any substantial problems. Further, by moving the power generation process away from the vehicles to stationary power plants, GEVs also provide the opportunity to continue improving the emissions profile of our surface transportation system by improving the emissions profile of our electric power generating stations, without any further modifications to the fleet.

FIGURE 3K AVERAGE DAILY ELECTRICITY DEMAND, 2030



Source: PRTM Analysis

FIGURE 3L U.S. ELECTRICITY CONSUMPTION (ALL SECTORS)



Source: PRTM Analysis

3.2 Total Cost of Ownership



While upfront costs for GEVs are currently high, battery costs will fall as technology advances, as more vehicles are produced, and as economies of scale are achieved. Over time, the use of electricity as a propulsion fuel will reduce the cost of owning, operating, and maintaining a GEV so that it is more cost effective than a conventional vehicle.

3.2.1 BATTERIES

The most substantial obstacle facing grid-enabled vehicles today is cost. Based on an industry-wide survey, the current average lithium-ion battery production cost is roughly \$600 per kilowatt hour. This is a largely generic average that ignores both chemistry and variable factors of production, such as labor costs (a battery manufactured in China will be less expensive than one manufactured in the United States). For a pure electric vehicle with a 30 kWh battery, therefore, today's battery costs equate to \$18,000 in battery cost alone. For a PHEV with a 16 kWh battery, the incremental battery cost is \$9,600.

These upfront costs are a significant capital outlay for most consumers. Existing government tax credits entitle consumers to tax credits for both PHEVs and EVs. Specifically, the minimum battery size of 5 kWh qualifies for a base credit of \$2,917. Each additional kWh of battery size qualifies for an additional \$417 up

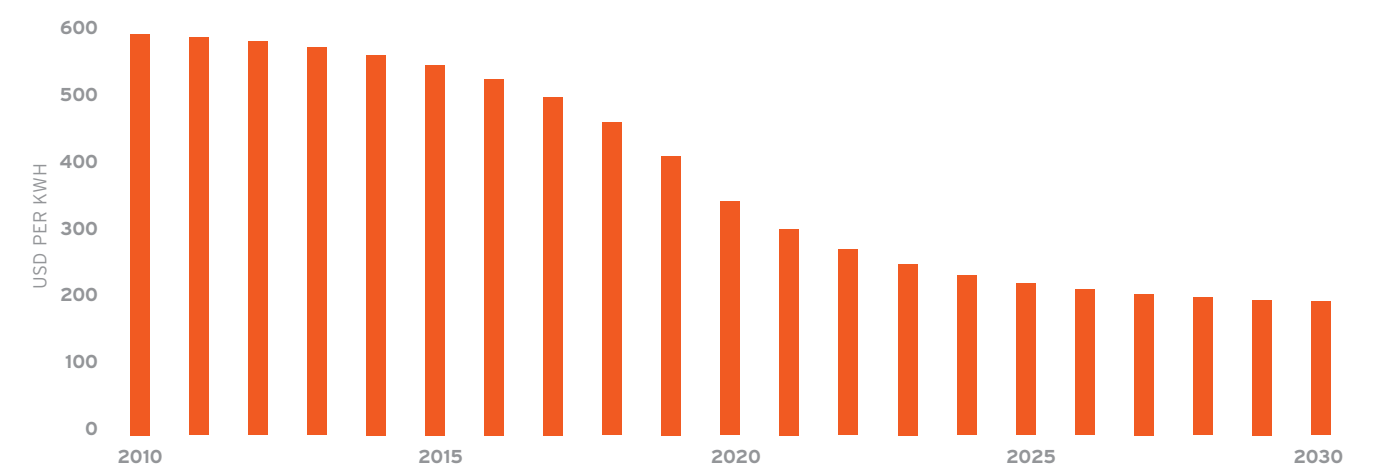
to a maximum credit of \$7,500. The credits are currently designed to be phased out once a manufacturer reaches 200,000 qualified vehicles sold.

To be sure, the existing federal incentives can go a long way toward reducing battery costs. Yet, even vehicles that qualify for the full credit will require a higher capital outlay by early GEV adopters. Therefore, it is impossible to imagine that GEVs will reach significant levels of market penetration in the absence of falling battery costs. For the purposes of this Roadmap, we have assumed the battery cost profile depicted in Figure 3M below.

3.2.2 OTHER VEHICLE COMPONENTS

In addition to the battery, both PHEVs and EVs will require additional vehicle components not found in traditional IC engine vehicles. In particular, these include an electric motor, a power inverter, an on-board charger, and more robust powertrain electronics

FIGURE 3M GEV BATTERY COST CURVE



Source: PRTM Analysis

specifically designed for GEVs. These components add to the cost of grid-enabled vehicles, though the cost of each of these components is expected to decline over time. For the purposes of this analysis, we have assumed the cost profiles presented in Figure 3N.

At the same time, GEVs will *not include* a number of components that are traditionally found in IC engine vehicles. PHEVs will have a down-sized combustion engine and reduced transmission costs. EVs will avoid an engine entirely, and will also not require an exhaust system or fuel tank. These savings are presented in Figure 3O.

3.2.3 UPFRONT COST ESTIMATES

The incremental battery costs and net effect of added and subtracted vehicle component costs have different impacts on PHEVs and EVs. PHEVs will not avoid many of the costs of traditional IC engine vehicles. However, by utilizing smaller batteries and downsizing many of the powertrain components, PHEVs will be less expensive in terms of upfront costs than pure EVs. (Of course, this assumes the traditional vehicle ownership model remains intact, which may or may not be the case.)

Combining the cost of the battery with the net effect of vehicle component costs yields the expected incremental cost curves depicted in Figures 3P and 3Q. For the EV, we have assumed a 30 kWh battery and for the PHEV a 16 kWh battery. The battery cost curve

FIGURE 3N COST OF ADDITIONAL GEV COMPONENTS*

	ELECTRIC MOTOR COST (\$)	INVERTER COST** (\$)	SINGLE SPEED TRANSMISSION (\$)	ON-BOARD CHARGER COST (\$)
2010	888	1,365	400	462
2011	801	1,193	400	444
2012	736	1,066	400	431
2013	688	972	400	421
2014	653	902	400	413
2015	626	850	400	408
2016	607	812	400	404
2017	593	783	400	401
2018	582	762	400	399
2019	574	747	400	397
2020	568	735	400	396
2021	551	722	400	389
2022	534	708	400	383
2023	518	695	400	376
2024	501	681	400	370
2025	484	668	400	363
2026	467	654	400	356
2027	450	641	400	350
2028	434	627	400	343
2029	417	614	400	337
2030	400	600	400	330

* Additional components required by GEVs that are not required in IC engine vehicles

** (Includes DC-DC Converter & High Voltage Bus)

Source: PRTM Analysis

FIGURE 3O COST OF AVOIDED ICE COMPONENTS*

	AVERAGE ENGINE COST (\$)	TRANSMISSION COST (\$)	EXHAUST SYSTEM COST (\$)	FUEL TANK COST (\$)
2010	1,450	1,200	600	100
2011	1,435	1,190	598	99
2012	1,420	1,180	595	98
2013	1,405	1,170	593	97
2014	1,390	1,160	590	96
2015	1,375	1,150	588	95
2016	1,360	1,140	585	94
2017	1,345	1,130	583	93
2018	1,330	1,120	580	92
2019	1,315	1,110	578	91
2020	1,300	1,100	575	90
2021	1,295	1,095	573	89
2022	1,290	1,090	570	88
2023	1,285	1,085	568	87
2024	1,280	1,080	565	86
2025	1,275	1,075	563	85
2026	1,270	1,070	560	84
2027	1,265	1,065	558	83
2028	1,260	1,060	555	82
2029	1,255	1,055	553	81
2030	1,250	1,050	550	80

* Components not required in GEVs that would typically be required in an IC engine vehicle



depicted in Figure 3M is assumed. Through 2020, the effect of ARRA consumer tax credits is also depicted.

3.2.4 OPERATING COST

Over the life of the vehicle, both PHEVs and EVs will provide consumers with substantial cost savings, particularly in terms of fuel. Operating a vehicle on electricity in the United States is considerably less expensive than operating a vehicle on gasoline. In large part, this is due to the high efficiency of electric motors, which can turn more than 90 percent of the energy content of electricity into mechanical energy. In contrast, today's best internal combustion engines have efficiency ratings of just 25 to 27 percent. In a relatively efficient current-generation IC

engine vehicle (30 miles per gallon) with gasoline at \$3.00 per gallon, the per-mile operating costs are 10 cents per mile. In today's generation of pure electric vehicles, assuming an average electricity price of 10 cents per kilowatt hour, the operating costs are 2.5 cents per mile.

For the purposes of this analysis, we have assumed the fuel cost profiles depicted in Table 3R. The average gasoline price is consistent with the Department of Energy's long-term price of crude oil as presented in the 2009 Annual Energy Outlook. Conventional IC engines are assumed to steadily increase in fuel-efficiency. The fleetwide average for new vehicle sales reaches 37 mpg in 2016, consistent with the Obama Administration's proposed efficiency rules released in

FIGURE 3P ADDITIONAL UPFRONT EV COST

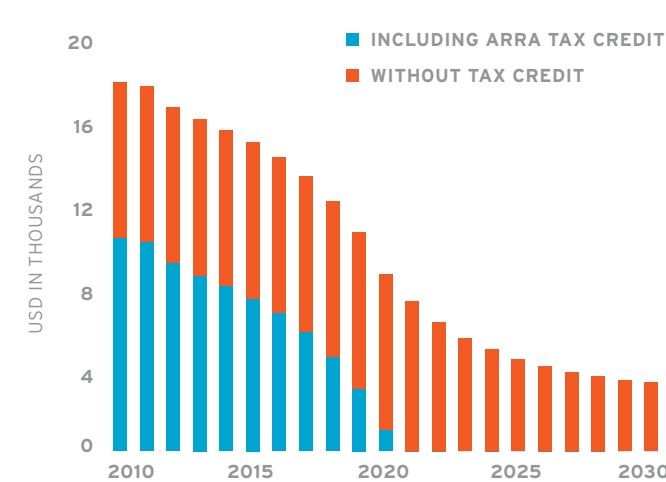
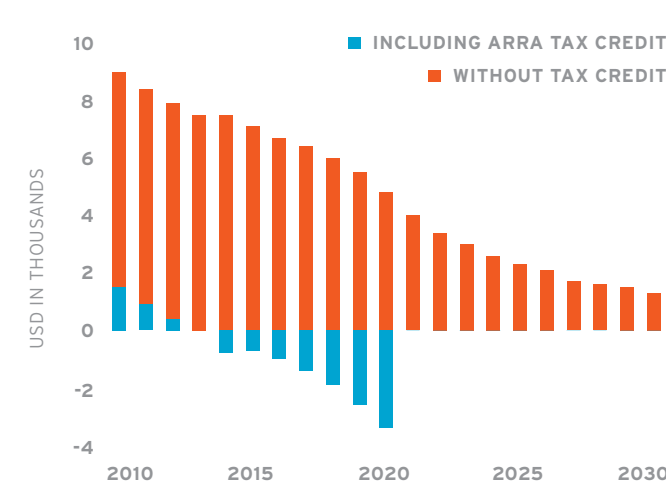


FIGURE 3Q ADDITIONAL UPFRONT PHEV COST



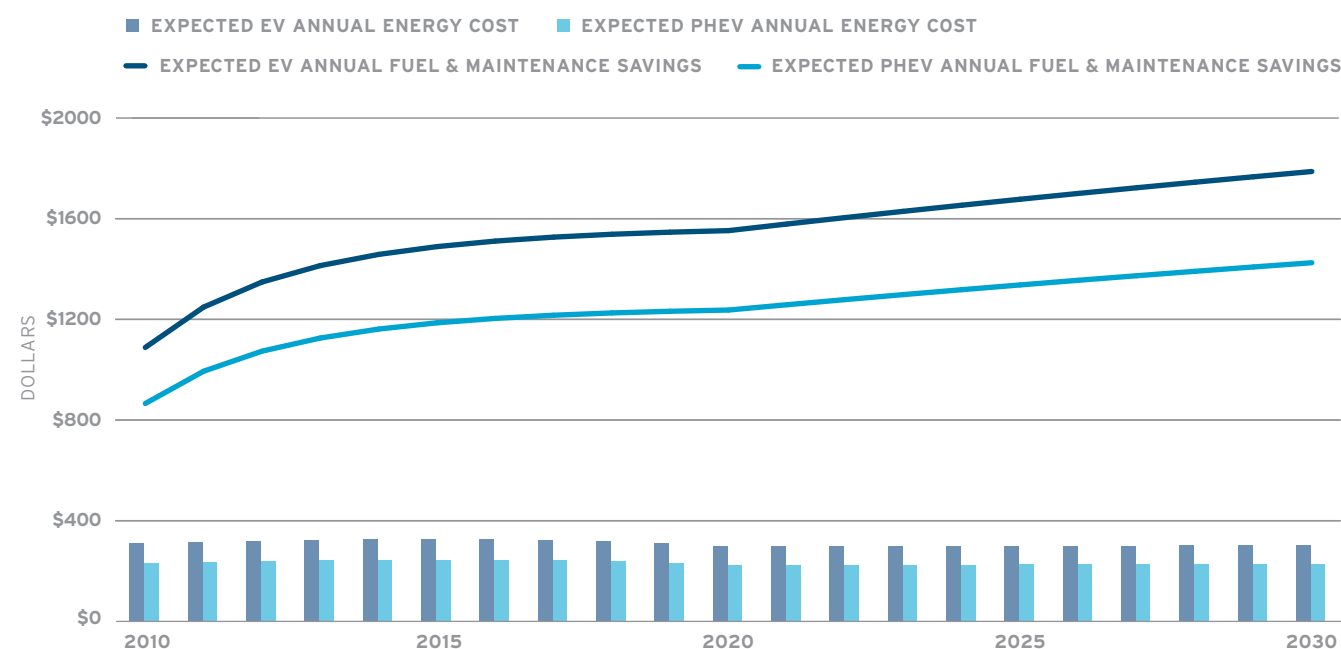
Source: PRTM Analysis

FIGURE 3R ENERGY PRICES

	AVERAGE GASOLINE PRICE (\$/GAL)	AVERAGE IC ENGINE FUEL EFFICIENCY (MPG)	AVERAGE PEAK ELECTRICITY PRICE (\$/KWH)	AVERAGE OFF-PEAK ELECTRICITY PRICE (\$/KWH)	AVERAGE ELECTRIC MOTOR EFFICIENCY (MI/KWH)
2010	2.22	27	0.12	0.08	4.0
2011	2.87	30	0.12	0.08	4.0
2012	3.35	32	0.13	0.08	4.0
2013	3.71	34	0.13	0.09	4.1
2014	3.97	35	0.13	0.09	4.1
2015	4.17	36	0.14	0.09	4.2
2016	4.31	37	0.14	0.09	4.3
2017	4.42	37	0.15	0.09	4.4
2018	4.50	38	0.15	0.10	4.5
2019	4.56	38	0.16	0.10	4.7
2020	4.60	38	0.16	0.10	5.0
2021	4.74	39	0.16	0.10	5.1
2022	4.89	39	0.17	0.10	5.1
2023	5.03	40	0.17	0.10	5.2
2024	5.18	40	0.17	0.10	5.2
2025	5.32	41	0.17	0.10	5.3
2026	5.47	41	0.18	0.11	5.3
2027	5.61	42	0.18	0.11	5.4
2028	5.76	42	0.18	0.11	5.4
2029	5.90	43	0.19	0.11	5.5
2030	6.05	43	0.19	0.11	5.5

Source: PRTM Analysis

FIGURE 3S COMPARISON OF GEV OPERATING COSTS



Source: PRTM Analysis

September 2009. By 2030, new IC engine light-duty vehicles average 43 mpg.

We assume electricity prices vary by peak and off-peak. Peak charging rates are assumed to be significantly higher than off-peak, reaching nearly 20 cents per kWh in 2030. Electric motor efficiency increases by slightly more than 20 percent between 2010 and 2030.

These estimates yield the operating costs depicted in Figure 3S. Annual energy savings from reduced gasoline consumption are highest for EVs, which use no gasoline. By 2030, annual gasoline savings for EV drivers reaches nearly \$2,000. It is assumed that 75 percent of the miles traveled by PHEVs will be electric miles.

Electricity consumption offsets the savings from reduced gasoline consumption. Annual energy costs are slightly lower for EVs than for PHEVs, but are steady at roughly \$325 throughout the forecast period. As electricity prices increase, motor efficiency also increases, partially offsetting the high cost of energy. For PHEVs, annual electricity costs are slightly lower than for EVs, because these vehicles will still rely on gasoline for an estimated 25 percent of VMT. Therefore, total PHEV energy savings are less than those for pure EVs.

3.2.5 TOTAL COST OF OWNERSHIP

Total cost of ownership (TCO) combines the full cost structure of grid-enabled vehicles for consumers. That is, the total cost reflects the initial capital outlay for a GEV and the expected lifetime operating costs. TCO is presented as operating costs per mile. To assess the market viability of PHEVs and EVs, it is useful to compare the total cost of ownership for GEVs to conventional IC engine vehicles. For this analysis, we include the cost of one dedicated (home) charging point. We also assume the battery profile and other component cost structures discussed above in this section. Other key assumptions are presented in Table 3T.

FIGURE 3T ADDITIONAL ASSUMPTIONS

	2010	2020	2030
Average Driving Distance (mi/year)		12,000	
Vehicle Life (years)		10	
PHEV CD Usage (% of miles driven)		75%	
Charging Power (kW)		3.3	
Charging Efficiency (%)		85%	
Off-Peak / Peak Charging Mix (% Off-Peak)	80%	90%	90%
Private Infrastructure Investment Requirements (\$/user)	700	350	300

Source: PRTM Analysis

A GAS TAX COULD SPEED GEV ADOPTION IN THE UNITED STATES

The primary challenge that GEVs will need to overcome if they are to penetrate the market significantly and not be relegated to a niche market is their high upfront cost, much of which is attributable to the cost of the battery. This challenge is exacerbated by relatively low gasoline prices in the United States. The average gasoline tax in the United States is 47 cents per gallon—18.4 cents of which is a nationwide federal tax. Fuel taxes in many other developed countries are significantly higher. In the United Kingdom, for example, the rate is equivalent to \$3.28 per gallon, almost 20 times as large as in the United States. Because the price of gasoline is much higher in most other developed countries, GEVs are much more cost competitive as compared to traditional IC engine powered vehicles. In most other developed countries, GEVs will have a lower total cost of ownership than IC engine powered vehicles almost from the moment they hit the market.

Fuel price volatility also acts as a disincentive for American drivers to switch to more fuel efficient vehicles because experience suggests that high prices are unsustainable. Consider the volatility in 2008, when average gasoline prices reached more than \$4.30 per gallon in mid-summer. By October 2008 they had fallen back below \$3 per gallon and before the end of the year were less than \$2 per gallon—a drop of more than 50 percent in less than 6 months. In countries where gasoline taxes are higher, however, volatility was considerably less as prices tended to fluctuate between \$7 and \$9 per gallon. The expectation of American drivers that high prices are unsustainable reduces the economic incentive to invest in efficiency. Therefore, even in periods of rising or high prices, American drivers may be uninterested in moving into more efficient vehicles.

Economists and political observers from Thomas Friedman on the left to N. Gregory Mankiw and Charles Krauthammer on the right have argued that a higher gasoline tax would help the United States to accomplish a number of national goals, including reducing oil dependence and lowering carbon emissions.

A higher, equitable, and sustained gas tax is arguably the most transparent and direct policy path to assist GEV market penetration, which would under a range of scenarios provide benefits to taxpayers far in excess of the cost. However, the substantial likelihood of a rapid repeal of such taxes in the early years after enactment for political reasons, as well as the political difficulties of enacting a gas tax increase at a level that would have a dramatic impact, argue for a GEV deployment plan that assumes gas taxes at the current level.

FIGURE 3U PHEV VARIED BY BATTERY SIZE (INCLUDING ARRA TAX INCENTIVE)

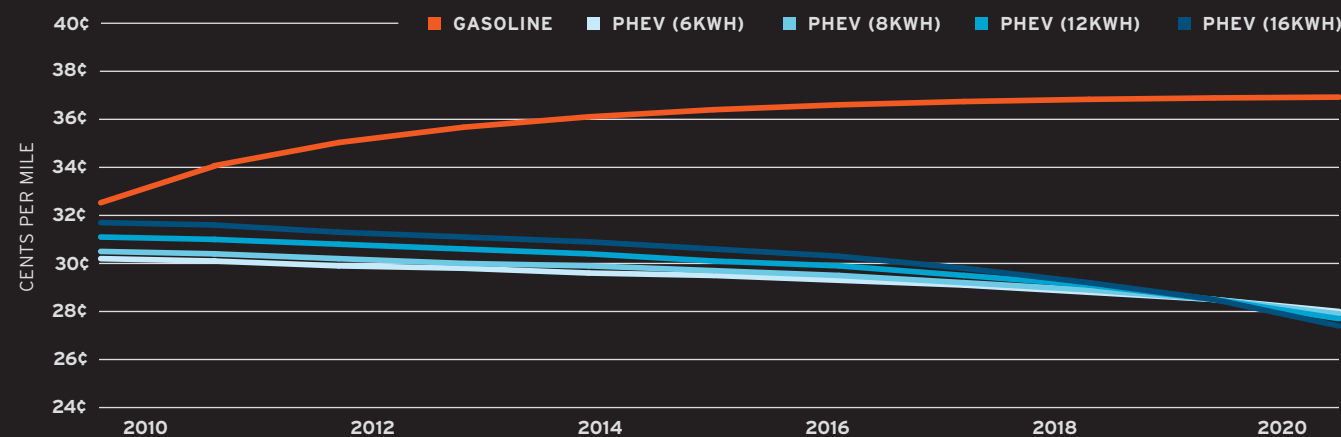


FIGURE 3V EV VARIED BY BUSINESS MODEL (INCLUDING ARRA TAX INCENTIVE)

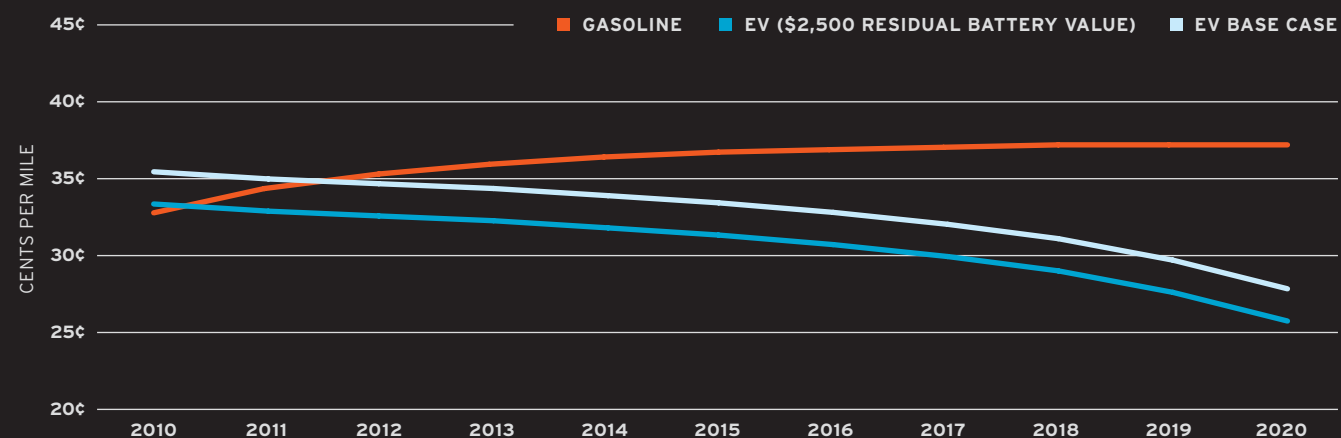
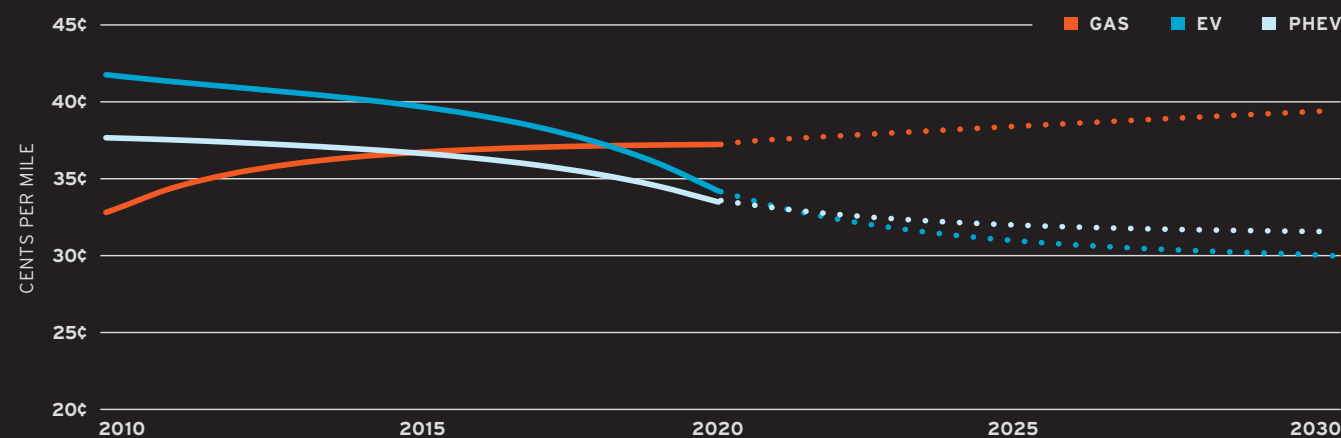


FIGURE 3W GAS VS. EV AND PHEV THROUGH 2030 (NO TAX INCENTIVES)



Source: PRTM Analysis

Plug-in Hybrid

Figure 3U presents the TCO analysis for PHEVs through 2020. Incorporating the ARRA consumer tax incentives, PHEVs already present a compelling value proposition for consumers. Across a range of potential battery sizes and consequent tax credit values, the total cost of ownership for a PHEV purchased today is less than for a comparably sized IC engine vehicle. In the coming years, as the costs of batteries and other vehicle components fall, and as gasoline prices rise, the value proposition presented by PHEVs will continue to improve.

This analysis assumes that tax credits provided by ARRA are no longer available after 2020. Yet, as can be seen in Figure 3W, by 2015 PHEVs reach parity with IC engine vehicles even without consumer tax incentives. To be sure, the higher upfront vehicle costs will present a significant financial hurdle for some consumers. Still, it is important to recognize that PHEVs are cost-effective early in the lifecycle of electric vehicle technology. Beyond 2020, as battery costs continue to decline and gasoline prices rise, the value proposition increases.

Pure Electric Vehicle

The proposition for pure electric vehicles is somewhat different. Because EVs will incorporate a much larger battery to achieve reasonable range, today’s higher battery costs make the TCO for pure EVs uneconomical, even with the maximum \$7,500 ARRA consumer tax incentive. Given this cost structure, it is certainly possible that automotive OEMs may choose alternatives

to the traditional vehicle ownership business model. Specifically, battery financing may be required to support early EV volumes envisioned in this Roadmap. In addition, the large size of EV batteries makes them especially suitable for secondary applications—in the power sector, for example. Therefore, the total cost of ownership of pure EVs through 2020 is presented in two cases:

1. A base case with the standard ARRA credit; and
2. The base case plus an assumed \$2,500 residual battery value.

For these cases, we assume an EV with a 30 kWh battery. Through 2020, all results incorporate the maximum ARRA tax credit. The results are displayed in Figure 3V. Not until 2012 do EVs reach cost parity with conventional IC engine vehicles in the base case. In the “residual battery value” case, however, EVs are close to cost parity with traditional IC engine vehicles today.

Over the longer term, even in the traditional ownership model, EVs are the most cost-effective solution for consumers. ARRA tax credits are assumed to end in 2020. Even without consumer tax incentives, EVs are cost competitive with IC engine vehicles by 2018. After that point, the value proposition increases as battery costs fall and gasoline prices rise. Moreover, as presented in Figure 3W, after 2020, pure EVs are more cost-effective than PHEVs over the life of the vehicle.

PART FOUR

Strategic Deployment

👁 4.1 OVERVIEW

➡ 4.2 DEMONSTRATION PROJECTS

➡➡ 4.3 PHASE ONE: 2010-2013

➡➡ 4.4 PHASE TWO: 2014-2018



An electric vehicle charging at the pier in Santa Monica, California. Particularly in the early years of grid-enabled vehicle deployment, consumers may demand access to pervasive public charging equipment.

ABSTRACT

Strategic Deployment

Early adopters will eagerly purchase the first grid-enabled vehicles once they hit the market. The primary challenge will be in expanding the market beyond these narrow groups to the general population of drivers. This will ensure that GEVs have a meaningful impact on U.S. energy security and that they do not become niche products.

To facilitate that process, the government should launch a select number of electrification ecosystems—communities chosen on a competitive basis in which resources are concentrated in order to promote the deployment of GEVs. In doing so, a range of market participants can work together to demonstrate that GEVs meet drivers' needs. Ecosystems will also allow participants to learn which business models work for supplying, selling, and servicing GEVs and help to create economies of scale. The lessons learned in electrification ecosystems can serve to inform other communities, thereby lowering the cost of deployment and accelerating national deployment rates.

4.1 Overview



Concentrating government resources in a small number of communities to serve as electrification ecosystems provides the United States the best opportunity to deploy a large number of GEVs as quickly as possible and achieve President Obama's goal of placing 1 million electric vehicles on the road by 2015.

An ambitious federal initiative to establish Electrification Ecosystems in a number of American cities is the best path to achieve deployment of grid-enabled vehicles at a level consistent with the goals of this Roadmap. An ecosystem is a group of interdependent entities that work or interact together to accomplish a common task or goal. In the GEV context, an electrification ecosystem is a region in which each of the elements necessary for the successful deployment of grid-enabled vehicles is deployed nearly simultaneously in high concentrations. By ensuring that vehicles, infrastructure, and the full network of support services and technologies arrive in well-defined markets together, ecosystems will provide an invaluable demonstration of the benefits of integrated electrification architecture.

The government has accelerated its support for electric vehicles over the course of this year with substantial funding for GEV-related activities in the American Recovery and Reinvestment Act of 2009 and additional proposals in legislation currently pending before Congress. This report, however, proposes an effort that is:

1. Larger and more comprehensive by an order of magnitude than programs already in place; and
2. More strategically focused than the programs that are underway or proposed in draft legislation.

For instance, in April 2009, the Energy Information Administration updated its energy-related forecasts to reflect the expected impact of the American Recovery and Reinvestment Act. Despite the ambitious GEV-related provisions in the legislation, EIA estimates that by 2030 there will be only 4.3 million GEVs on the road, representing less than 1.5 percent of the fleet.¹

In sharp contrast to current Department of Energy forecasts, the goals stated in this report call for 14 million GEVs to be on the road by 2020 and more than 120 million by 2030, a far more ambitious and transformative target. To help meet that goal, this section outlines a set of policies designed to accomplish the phased implementation of electrification ecosystems in key metropolitan areas throughout the United States. This plan contrasts sharply with the government's traditional approach of spreading the initial benefits of its programs evenly across the country. By focusing the initial deployment of electric vehicles in a small number of communities, ecosystems will address many of the obstacles to electrification and accelerate the speed with which the nation achieves high rates of GEV penetration by a decade or more.

¹ AEO 2009, Supplemental Tables, Table 58 "Light-Duty Vehicle Stock by Technology Type."

4.2 Demonstration Projects

Investing in electrification ecosystems will allow all interested parties to work together to demonstrate the viability of GEVs and identify business models that will allow each portion of the GEV supply chain to operate profitably, while taking advantage of the economies of scale achievable by concentrating resources in a select number of communities.

At its essence, this plan calls for a series of large-scale demonstration projects. Demonstration projects are used to overcome the final hump in the innovation pathway. Their purpose is to stimulate the adoption and use of a particular technology by proving that it “works.” Demonstration projects are used when a technology has clear potential benefits, but private sector actors face high risks in the technology’s deployment. The government assumes the risk and the cost burdens in part or whole. Demonstration projects are distinguished from field testing in that they do not employ embryonic or nascent technology; that is, demonstrations that are effective and successful prove market readiness for fully qualified products, as opposed to premature production prototypes.²

Premature technologies are at the root of many of the U.S. government’s failed attempts at energy technology demonstration. In 1971, for example, President Richard Nixon committed to the construction of a second generation of nuclear power technology, the Liquid Metal Fast Breeder Reactor (LMFBR). The basic design and construction of a LMFBR was largely unverified at the project’s outset, yet the stated intention of the project was a commercial plant with a net electrical output of 350 MW by 1980.³

When the Atomic Energy Commission (AEC) and a group of utilities joined forces to build the reactor, they found it considerably more technically challenging than expected. It also used plutonium in an

environment of sinking uranium prices.⁴ Costs escalated from the initial estimate of \$2.6 billion to more than \$6.7 billion (in 2008 dollars).⁵ Furthermore, the reprocessed plutonium was much more easily convertible into weapons-grade fuel than conventional uranium. The combination of security risks, escalating construction costs, and the 1979 Three Mile Island accident led to the congressional termination of funding in 1983, prior to project completion.⁶

Successful demonstration projects require a different approach. Since 1834, when Congress appropriated \$30,000 to prove Samuel Morse’s telegraph system,⁷ the government has successfully carried out many demonstration projects, usually in partnership with the private sector and university research programs. These projects have led to commercialization of a wide variety of vital technologies. For example, the Department of Energy’s Advanced Turbine Systems demonstration projects in the early 2000s led to what are now state-of-the-art commercial integrated gasification combined cycle (IGCC) power plants. In general, experience has shown that public demonstration projects are most successful when:

1. cost and administrative burdens are shared between the public and private sectors;⁸

² M.A. Brown et al, “Demonstrations: The Missing Link in Government Sponsored Energy Technology Deployment.” *Technology in Society*, Vol 15, pp. 185-205, 1993.

³ International Atomic Energy Agency, “Nuclear Power Reactor Detail – Clinch River” PRIS Database, available at www.iaea.org/cgi-bin/db.page.pl/pris.prdeta.htm?country=US&refno=537, last accessed September 10, 2009.

⁴ Sokolski, Henry, “The Clinch River Folly,” *The Heritage Foundation Background #231*, December 3, 1982.

⁵ Lefevre, Stephen R. 1984. *Using Demonstration Projects to Advance Innovation in Energy*. Public Administration Review. November/December 1984. p. 488.

⁶ U.S. Department of Energy, “Energy Timeline,” available at www.energy.gov/about/timeline1971-1980.htm, last accessed September 10, 2009.

⁷ Lefevre, Stephen R. 1984. *Using Demonstration Projects to Advance Innovation in Energy*. Public Administration Review. November/December 1984. pp.483-490.

⁸ Baer, Walter S., Johnson, Leland L., and Edward Merrow. 1977. *Government Sponsored Demonstrations of New Technology*. Science



2. results are adequately disseminated;
3. clear project goals are agreed upon by the relevant parties; and
4. the technology is mature with minimal unknowns.⁹

Demonstrations are especially useful when both the industry and end-user markets are highly fragmented. In this case, demonstrations can establish links in the supply chain and connect decision-making around production and consumption.¹⁰ Ideally, demonstration projects should penetrate existing markets, creating a “demand pull” for the technology as well as a “technology push,” or learning gains that improve the rate of technological progress. For electric vehicles, this means connecting the electricity suppliers with the vehicle manufacturers, establishing a business model for charging infrastructure, and then deploying the entire system in a way that meets consumers’ needs.

4.2.1 THE CASE FOR ESTABLISHING ELECTRIFICATION ECOSYSTEMS

Electrification ecosystems will accomplish three important goals. They will:

1. prove that widescale deployment of grid-enabled vehicles is not only possible, but desirable;
2. take advantage of economies of scale; and
3. support research to answer critical questions about vehicle usage and recharging patterns.

Proof of Concept

By demonstrating the benefits of grid-enabled vehicles in a real world environment, electrification ecosystems will make consumers, policymakers and industry aware of the tremendous potential of electrification of transportation. Most Americans are familiar with traditional hybrids, having seen them on the road for most of the past decade; far fewer drivers are familiar with electric vehicles. In general, consumers are probably unaware that GEVs have evolved to the point where they can meet most individuals’ daily driving needs. In addition,

196. p 954-955

⁹ Lefevre, Stephen R. 1984. *Using Demonstration Projects to Advance Innovation in Energy*. Public Administration Review. November/December 1984. p 488

¹⁰ M.A. Brown et al, “Demonstrations: The Missing Link in Government Sponsored Energy Technology Deployment.” *Technology in Society*, Vol 15, pp. 185-205, 1993.

electric drive vehicles generally have faster acceleration and operate more quietly than internal combustion engine vehicles. They hold out the promise of offering drivers a wide range of features, based on the electronic package in the vehicle, that are beyond our imagination today in the same way that iPhone applications would have been beyond our imagination a decade ago. The problem is that consumers are not aware of the opportunities presented by GEVs and are not yet convinced that they can operate reliably and affordably at scale.

Electrification ecosystems conform to the basic goal of traditional demonstration projects. Concentrating investments and other efforts in a limited number of communities will accelerate the opportunity to demonstrate that grid-enabled vehicles can meet drivers’ needs. Ecosystems will demonstrate that a community is capable of putting the infrastructure in place, operating the vehicles over their lifetimes, and disposing of them after their useful life has ended, all in a manner that profits the participants in the value chain. In short, electrification ecosystems provide the best opportunity to give consumers confidence in the safety, performance, and benefits of the vehicles themselves and the reliability of the surrounding infrastructure.

Economies of Scale

Concentrating resources in a limited number of electrification ecosystems will allow participants in the GEV value chain to take advantage of economies of scale, particularly with respect to the deployment of a vehicle charging infrastructure. Utilities will incur fixed costs to support the operation of GEVs; those costs will be more affordable if spread over a greater number of vehicles. Power providers also can reduce the cost of charging infrastructure through economies of scale. While it is unclear how many public vehicle chargers will be necessary for a GEV ecosystem to operate smoothly, it is clear that some public charging facilities will be needed. Previous pilot studies demonstrate that the cost of installing charging

Demonstrations are useful when industry and end-user markets are fragmented.

facilities can be reduced significantly when groups of facilities are installed at once.

Furthermore, electrification ecosystems will stimulate demand for grid-enabled vehicles at a rate that is likely to be far in excess of the rate if the vehicles are simply purchased by early adopters scattered around the United States. Early on in the process, this higher level of demand will simply be the result of magnified

Concentrating investments in a limited number of communities will accelerate the opportunity to demonstrate that grid-enabled vehicles can meet drivers' needs.

consumer incentives (discussed below). Subsequently, as individual metropolitan areas gain exposure to GEVs and confidence increases, adoption rates should be measurably expedited.

Learning by Doing

While GEVs present a great opportunity, their deployment also raises a number of questions. Deploying large numbers of GEVs in concentrated areas will allow for the collection of information and experience that is needed to successfully deploy GEVs nationwide. It will help automakers learn how much consumers are willing to pay up front for a car that costs less to operate and has a lower total cost of ownership over its lifetime. It will allow utilities and charging station providers to learn when and where drivers want to charge their vehicles. It will allow utilities and other aggregators to learn who can best sell power to drivers and what types of rate structures meet both drivers' and utilities and aggregators' needs. It will help determine whether there is a viable business model for public charging infrastructure.

It is clear that for GEVs to succeed there must be a model in which each party in the value chain is able to operate profitably, or in which the government determines that, as a matter of public policy, certain aspects of the system should be publicly supported in a manner that facilitates further competition. At this point it is not possible to answer many of the critical questions

needed to build out the system at scale. While there have been numerous studies modeling the full range of GEV characteristics under varying scenarios, all of the studies to date have been relatively small.¹¹ Because of their size, it is unlikely that study participants were representative of typical consumers.

Deploying GEVs in a series of ecosystems around the country where resources can be concentrated and data can be collected and studied will ultimately accelerate widescale GEV deployment. Therefore, rather than allowing the market to develop scattershot across the country, it is critical that the market be encouraged to develop at a deliberate pace in clearly identified geographic regions in which a large number of vehicles can be deployed in a relatively short period of time.

4.2.2 ECOSYSTEM SELECTION

Electrification ecosystems should be chosen on a competitive basis with an application that mirrors the core components of, for example, an International Olympic Committee bid. Successful bids would ideally be submitted by a coalition of entities in a metropolitan area reflecting wide support for GEV deployment. Such coalitions should include support from:

State and Local Governments

State and local governments would be expected to commit some funds, or offer some consumer incentives, and to help streamline issues regarding infrastructure deployment. They might, for instance, establish a streamlined permitting process for installation of EVSEs in private homes and for installing public charging infrastructure; commit to the installation of charging infrastructure whenever sidewalks are being rebuilt; commit to a minimum purchase requirement for state and local government fleets; offer reduced registration charges or sales taxes for GEVs; or offer free public parking to GEVs.

Local Public Utility Commission

A state utility regulator would be expected to allow the local utility to add the costs of IT infrastructure necessary to manage the vehicle charging process into its rate base and to allow the utility to offer innovative

¹¹ A 2009 UC Davis study, for example, used fewer than 50 vehicles, which were placed in homes for six weeks, and data was only collected for the last two weeks of their use. BMW is currently performing a study of less than 500 vehicles over the course of one year. A similar study conducted by Google with company employees used fewer than 25 vehicles.



rates to help manage the GEV charging process. Such rates could include time-of-day pricing for homes with GEVs, time-of-day pricing only for that power used to charge GEVs, a flat charge for power used to charge GEVs, or other innovative ideas.

Local Utility(s)

The local utility would be expected to commit to install the hardware and software infrastructure to control the charging process and innovative rate tariffs for power for GEVs. It also would be expected to explain how it would use innovative rate structures, including, perhaps, time-of-day pricing, to help manage the charging process.

Large Local Employers

Universities, large manufacturers and other employers might participate by committing to provide charging facilities for employees who drive GEVs to work. A local car rental company might commit to convert a certain portion of its fleet to GEVs, and local hotels might commit to installing EVSEs for overnight guests.

Beyond these basic elements, it would be up to each community to develop ideas that further demonstrate a commitment to GEV deployment and will facilitate that process.

In addition to prestige, participating regions will derive a wide range of economic benefits from selection as an ecosystem. The funds that are provided to the electrification ecosystems to build infrastructure will certainly create new jobs and promote economic growth in the region. Deployment of GEVs also will reduce pollution and enhance air quality. Finally, successful ecosystems will benefit from a magnet effect. By demonstrating to observers that the community as a whole—government, leading businesses, and other leading civic institutions—is capable of coming together to achieve significant goals, ecosystems can promote the region's image as an attractive location for other high-tech industries.

In selecting demonstration ecosystems, DOE should evaluate a wide range of criteria. The criteria should include, but not be limited to:

- › A strong level of commitment to the project by state and local governments, utilities, utility regulators, local businesses and large employers.

- › The ability of all stakeholders to support the effort, financially and otherwise.

- › Evidence that the local economy is capable of achieving the targeted number of vehicles.

- › A demonstration that the community is a reasonable representation of other cities, demographically and otherwise, so that data collected about GEV deployment in that community would be informative about deployments elsewhere.

- › An understanding that the collection of cities chosen incorporates a diverse set of challenges and demographics (e.g., more urban vs. more suburban, hotter vs. cooler, different income levels, etc.) so that different lessons might be learned in different places.

- › Proximity to other communities to which GEV infrastructure could be expanded.

- › The extent to which the proposal leverages the investment of ARRA funds to construct GEV-related infrastructure.

In evaluating applications, DOE also should attempt to select communities that offer a range of approaches to the GEV deployment challenges. It should look for some communities in which utilities will sell power to customers and other cities in which aggregators will also sell power to customers. It should choose cities with entities that will support battery leasing and others that may not. Some cities might emphasize battery exchange while others might emphasize fast charging. Despite the different choices and business models that may be deployed in different electrification ecosystems, with the exception of battery exchange facilities, most of the infrastructure will be compatible across ecosystems, so that lessons from each city can be applied elsewhere.

4.3 Phase One: 2010–2013



Between 2010 and 2013, the government can help lay the groundwork for the deployment of 700,000 GEVs in six to eight American cities. The effort will require a combination of focused government subsidies for consumers and utilities, in addition to the installation of a public charging network and other measures of support.

Ecosystems will form the basis for widespread, nationwide deployment of grid-enabled vehicles. But the process must be carefully managed and precise in order to avoid falling into the same pitfalls as previous attempts at electrification (as outlined in Part One). Therefore, in phase one, the federal government should support between six and eight electrification ecosystems. Demonstrations should be undertaken in different parts of the country, in different climates, and in communities with different densities of urban and suburban residents.

Perhaps most important, it will be critical that individual ecosystems incorporate *diverse but compatible* business models in order to maximize “learning-by-doing.” Ideally, various models of consumer ownership—battery leasing, private ownership, network operator—will be represented in distinct ecosystems. At the same time, central coordination at the Department of Energy will be needed in order to ensure that as dominant designs come into focus, infrastructure and other key components of different ecosystems can be easily adapted.

Phase one ecosystems should each reach stock penetration rates of 50,000 to 100,000 vehicles by 2013. These figures would place the nation on a path to place a total of approximately 700,000 grid-enabled vehicles on the road by 2013. This rate of deployment is consistent with the early GEV adoption rates required to meet the national target envisioned by this Roadmap (75 percent of VMT electric by 2040). Moreover, in appropriately sized cities, this will represent a significant portion of newly-purchased vehicles. Massing that many vehicles in a limited number of communities will prove that GEVs can work at scale

and allow researchers to generate a large enough data set to evaluate GEV usage patterns.

4.3.1 DATA COLLECTION

A critical reason for supporting the deployment of GEVs through electrification ecosystems is the opportunity to learn about how typical drivers use and charge their vehicles. To support the learning process, a DOE Office of Electric Transportation should be responsible for collecting, organizing, and disseminating all of the data regarding the operation of GEVs. The government should also fund the direct costs of data collection activities incurred by non-governmental entities. The data would then be placed in the public domain so that industry participants and researchers could examine it in order to better understand the challenges facing GEVs and develop opportunities to overcome those challenges.

Once up and running, electrification ecosystems would serve as the learning centers in which all relevant participants in the GEV value chain could better understand how the system can work and how they can most profitably participate in it.

The interaction between grid-enabled vehicles and the electricity system will necessarily be a complex, two-way street of data using the internet and possibly GPS location technology. In order to charge vehicles and bill efficiently, utilities will likely have to collect data about when and where motorists are charging. During initial GEV deployment, charging pattern data will be vital to assessing future infrastructure and power generation needs, as well as learning about how to shape the power demand load and integrate renewable energy sources. However, it will be important to collect this data in a way that maintains consumer privacy.



FEDERAL FLEET PURCHASES OF GEVs



A Presidential limousine, part of the federal fleet.

As the largest consumer in the nation, with a presence that extends throughout the economy, the federal government is well situated to help establish the market for GEVs. The most recently issued executive order on the subject, Executive Order No. 13423, issued by President Bush in 2007, directed agencies with 20 or more vehicles to reduce their fleet fuel consumption by 2 percentage points annually from 2005 to 2015 (a 20 percent reduction).

Particularly in phase one electrification ecosystems, the federal government can play a critical role in terms of driving scale throughout the GEV production supply chain. By placing large orders that will turn over regional federal fleets, the government can contribute to an accelerated pace of technological advancement in battery production, driving down costs. Large fleet purchases will also give automotive and battery OEMs the long-term stability needed to justify significant investments in labor and equipment.

Congress, by statute, or the president, by executive order, should direct government agencies with a minimum fleet size to purchase GEVs whenever they are available and meet agency requirements. If suitable GEVs are not available, agencies should be required to choose among the three most efficient vehicles for each class of car as defined by the Environmental Protection Agency for the purpose of calculating fuel-economy standards. Doing so will promote the development of markets for vehicles that will enhance U.S. energy security.

4.4 Phase Two: 2014-2018



By 2014, the electrification ecosystem program should expand to an additional 20 to 25 cities. Target deployment should be 7 million GEVs by 2018. By employing lessons learned in phase one, phase two ecosystems can achieve greater scale at reduced cost.

Phase one of the ecosystem deployment strategy is intended primarily as a proof of concept and data collection exercise. The goal is to take advantage of economies of scale in a handful of cities to deploy relatively large numbers of GEVs in order to build consumer confidence and accelerate the learning process. The lessons learned in those communities will help other cities determine how much charging infrastructure is necessary and where it should go, when drivers will charge their vehicles, how much they are willing to pay to charge their vehicles, to what extent their charging patterns will be affected by the price of electricity, and which business models might be most successful.

In sharp contrast, phase two of the deployment strategy is intended to jumpstart the wide-scale adoption of grid-enabled vehicles in the United States. In order to remain on a path to reach the target envisioned by this Roadmap (75 percent of VMT electric by 2040), the Roadmap from 2014 to 2018 will need to initiate a significant turn-over of the U.S. vehicle fleet through high GEV sales volumes. The GEV milestones associated with the target call for 14 million grid-enabled vehicles on the road in 2020 and more than 120 million in 2030. Therefore, phase two will expand deployment to between 20 and 25 additional cities.

Phase two ecosystems should each reach stock penetration rates of 75,000 to 150,000 vehicles by 2018. At the same time, the initial phase one ecosystems should continue to grow and reach stock penetration rates of 400,000 to 500,000 vehicles by 2018. This level of adoption would place the nation on a path to deploy approximately 7 million grid-enabled vehicles on the road by 2018, consistent with the national goals set out in Part One of this Roadmap. By the end of phase two, the nation will be on target

to reach Milestone One, in which 25 percent of new light-duty vehicle sales are grid-enabled vehicles.

As the GEV concept is proved, consumer acceptance rises, battery costs decline, and infrastructure deployment becomes more efficient, government support in electrification ecosystems can also decline. As a general matter, the policies established to support phase one should be maintained, but they should be reduced in terms of intensity.

Of course, it will be critical that incentives are tied most closely to the targeted levels of GEV deployment consistent with national goals. In this sense, the timeframe for both phase one and phase two ecosystems is not intended as a strict guideline by which to structure government incentives. Congress and the Administration will ultimately need to assess the appropriateness of adjusting any ecosystem incentives based on the success of the program, the rate at which GEVs are being purchased, and the level at which charging and utility infrastructure components are installed.

POLICY RECOMMENDATIONS

Phase One



Create position of Assistant Secretary for Electric Transportation at the Department of Energy

Discussion: Congress should create the position of Assistant Secretary of Energy for Electric Transportation at the Department of Energy, and should increase from seven to eight the number of Assistant Secretaries that may be appointed at the Department. It would be the Assistant Secretary's responsibility to promote the deployment of GEVs. He or she also would be responsible for managing the ecosystem demonstration projects, coordinating across government agencies where necessary, and preparing annual reports on the progress of the ecosystems and other elements of a nationwide electrification process.

To assist the Assistant Secretary in the meeting of his or her responsibilities, the Office of Electric Transportation should open field offices in each city that is chosen as an electrification ecosystem (as described below) to serve as a central point of coordination between the community and the federal government and, if appropriate, within the community. The local office would also be responsible for collecting all of the data generated by the deployment of the GEV fleet and infrastructure in the ecosystems and making it available for research. Finally, the local office would be responsible for working with other stakeholders to undertake a public education program to explain and promote GEVs within the region.

POLICY RECOMMENDATIONS

Phase One



Modify plug-in electric drive vehicle tax credits by significantly increasing them for vehicles purchased and registered in phase one ecosystems

Discussion: The tax code currently offers a tax credit of between \$2,917 and \$7,500 for vehicles with batteries with a capacity of at least 5 kWh. Vehicles with batteries with a capacity of 5 kWh are eligible for the minimum \$2,917 tax credit. The credit increases by \$417 for each additional kWh of battery capacity. With the 2009 industry average for lithium-ion battery prices at about \$600 per kWh, the tax credit subsidizes at least two thirds of the cost of the battery. The tax credit begins to phase out for vehicles sold by a manufacturer after the manufacturer has sold 200,000 eligible vehicles.

Based on existing federal tax credits and an assumed battery price of \$600 per kWh, a 16 kWh PHEV-40 currently has a lower total cost of ownership than an internal combustion engine vehicle. Meanwhile, a 30 kWh pure EV will be cost competitive by 2012. Because of the higher upfront cost of the battery, however, the payback period for these vehicles is still beyond the point at which most consumers view the value proposition as compelling.

To facilitate deployment of GEVs in electrification ecosystems, the government will need to adjust existing consumer tax incentives enacted by the American Recovery and Reinvestment Act. The revised tax credit should fully eliminate the premium for the cost of a GEV over the cost of a conventional IC engine vehicle for vehicles registered in electrification ecosystems. The credit should be limited to no more than 50 percent of the cost of the vehicle including the battery. It should also decline over time, both to reward early adopters and to reflect the expectation that battery costs will fall as technology progresses. A declining credit could also provide an incentive for drivers who might not have been in the market for a new car in order to accelerate their purchase of a new electric vehicle.

FIGURE 4A REVISED GEV TAX CREDIT FOR LDVs REGISTERED IN ELECTRIFICATION ECOSYSTEMS

		EV	PHEV
Base Tax Credit		–	\$1,750
Additional per kWh Tax Credit	2011	\$587	\$607
	2012	560	548
	2013	536	500
	2014	513	460
	2015	491	424
	2016	465	388
	2017	434	350
	2018	394	305

The credit should be available to an unlimited number of qualified vehicles sold and entered into service in electrification ecosystems over the life of the tax credit. In order to ensure that all GEVs are capable of communicating with utilities with respect to vehicle charging, the Department of Energy should define a minimum standard for grid communications and the tax credit should only be available to GEVs that meet that standard, assuming that a standard is adopted in ample time to meet an auto manufacturer's production schedule. The existing tax credit should not be adjusted for GEVs registered outside of the GEV electrification ecosystems.

The law should be further modified to allow the consumer to receive the value of the tax credit as an instant rebate at the time of vehicle purchase, as was the case for rebates that the government offered in the Cash for Clunkers program in the summer of 2008. Making the subsidy available as a rebate instead of a tax credit lowers out-of-pocket costs, ensures that consumers do not have to finance the value of the tax credit, simplifies the process by eliminating any need to alter tax returns, and ensures that all consumers can obtain the full value of the subsidy, even if they do not pay sufficient taxes to take full advantage of the tax credit. Making GEVs significantly more cost effective in the electrification ecosystems would promote ecosystem development by concentrating resources.

Establish tax credits equal to 75 percent of the cost to construct public charging infrastructure in phase one ecosystems

Discussion: Next to the battery, one of the most significant costs in developing GEV ecosystems will be the cost of the public charging infrastructure. As discussed earlier, it is widely assumed that public chargers will be necessary in order to support a GEV ecosystem. Moreover, in order to facilitate public acceptance of GEVs, public charging facilities must be ubiquitous, at least at first. (Even PHEVs have a limited range of operation in charge-depleting mode.)

In order to address range anxiety and meet drivers' needs, public charging infrastructure should be deployed widely in electrification ecosystems. With the development of ecosystems, policy planners will be able to study and better understand driver charging patterns and the needs in a given area for public charging infrastructure. That information may show where and what type of public chargers are most widely used and where they should be deployed once GEV usage spreads beyond the electrification ecosystems; it may even show that less public charging infrastructure is needed than was initially believed. Either way, wide-scale deployment of the infrastructure in demonstration cities can inform the subsequent deployment of infrastructure elsewhere.

Because of the initial importance of such infrastructure, in particular, within the electrification ecosystems, the federal government should be prepared to pay for up to 75 percent of the cost of deployment. This will enable of the ubiquitous deployment of Level II and Level III public chargers (perhaps even to the point that they are not cost-effective) both to ease driver concerns about range anxiety and in order to generate data about how chargers in different places are used. Second, government funding of the infrastructure can help overcome the chicken and egg problem that drivers and private companies cannot realistically be expected to resolve themselves.

Extend consumer tax credits for home charging equipment

Discussion: As explained earlier, most vehicles spend most of their time parked at home, meaning that owners of GEVs will certainly want home charging capability. As also explained earlier, most drivers will want 220 volt charging, the installation of which could take significant time and be costly. In most instances (all of those where there is no 220 volt outlet in a home's garage, and perhaps some where there is already a 220 volt outlet in the garage) a professional electrician will be required to perform the installation. He or she will have to determine if there is space available in a home's electrical panel and run a wire from the panel to the charger. The electrician might also have to obtain a government permit for the work, which may be subject to government inspection.

This process will not only take time, it will impose a substantial cost on the consumer. The existing law offers consumers a tax credit of 50 percent up to \$2,000 for the installation of home charging devices for GEVs that enter service before the end of 2010. Congress should extend the existing tax credit for the installation of private charging infrastructure that is installed in an existing home in a community within an electrification ecosystem through the end of 2013. The credit should be reduced to a maximum of \$1,000 or 25 percent through 2018.

Establish tax credits up to 50 percent of the costs of the necessary IT upgrades for utilities or power aggregators to sell power to GEVs in phase one ecosystems

Discussion: Either electric utilities or consolidators that sell power for charging vehicles will need to make significant investment in an IT infrastructure to support GEVs. At a minimum, the infrastructure must be capable of performing two functions. First, it must be capable of starting and stopping the charging process at the direction of either the utility or the aggregator. Second, the systems must be capable of supporting customer billing for innovative rate schedules, such as time-of-day pricing, which may be desirable or even necessary to optimize the operation of the grid. The IT infrastructure could be designed to support an almost limitless range of additional services that can enhance consumer utility and grid operations. But controlling the charging process and support for innovative rate structures represent a minimum capability for every utility's or aggregator's investment.

As explained earlier, electric utilities have excess generating capacity during overnight hours, and lesser amounts of spare capacity during the morning and early afternoon. Distribution utilities may also have localized capacity challenges at the neighborhood transformer level. In addition to upgrading transformers where necessary, the primary goal for utilities or electricity aggregators should be to manage the charging process so that it makes best use of existing excess capacity, obviating the need for capacity upgrades until absolutely necessary. For instance, utilities not only want to promote overnight vehicle charging, but should try to schedule the charging of vehicles in a staggered manner so as to flatten the load curve as much as possible.

The cost of such an IT infrastructure for a medium sized utility could run several million dollars. In order to facilitate the investment in the IT support necessary for a GEV ecosystem, the federal government should be willing to pay for up to half the costs of the necessary IT upgrades for utilities or power aggregators to sell power to GEVs.

POLICY RECOMMENDATIONS

Phase Two



In phase two, adjust consumer tax credits for GEVs and standardize them across phase one and phase two ecosystems

Discussion: Because battery prices will decline over time, GEV tax credits intended to offset the high cost of batteries also should continue to decline over time. The credits, therefore, should be reduced in size consistent with the tax credit schedule outlined in the discussion of phase one. Eligibility should be expanded to all GEVs registered in phase one and phase two communities. Tax credits for GEVs registered outside of phase one and phase two communities, however, should remain at significantly reduced levels.

In phase two, adjust tax credits for public charging infrastructure to approximately 50 percent of the cost

Discussion: Tax credits for public charging infrastructure during phase one were set to pay for 75 percent of the infrastructure costs. Phase two ecosystems should benefit from higher consumer confidence in GEVs, defined value propositions for EVSE, and a complete data set that allows for more strategic deployment of recharging units. Because each of the factors work together to both reduce the overall cost of infrastructure and the risk associated with it, tax credits for public charging infrastructure should be reduced to 50 percent for infrastructure installed in phase two communities.

In phase two, adjust financial support to 20 percent of the cost for IT upgrades for utilities or power aggregators to sell power to GEVs

Discussion: Utilities or aggregators in phase two communities will need to install the same infrastructure that utilities in phase one cities installed in order to control the charging process, and must deploy systems capable of supporting customer billing for innovative rate schedules, such as time-of-day pricing. Such equipment will remain expensive. Because, however, much of the equipment is dual use, also providing the capabilities to provide a wide range of "smart grid" services, and because those capabilities will be further advanced by the time phase two begins, the federal support for installation of such capabilities should be reduced to 20 percent. Moreover, by the time phase two is underway, the concept of GEVs should be proven and utility regulators should allow utilities to include investments in IT infrastructure to support GEVs in their rate base.

Conclusion

Hostile state actors, insurgents, and terrorists have made clear their intention to use oil as a strategic weapon against the United States. Steadily rising global oil prices add to the danger by exacerbating tensions among consuming nations. And excessive reliance on oil constrains the totality of U.S. foreign policy and burdens a U.S. military that stands constantly ready as the protector of last resort for the vital arteries of the global oil economy.

Our dependence on oil not only undermines our national security and the conduct of our foreign policy, it undermines our economic strength. High and volatile prices result in the loss of hundreds of billions of dollars in our economy each year; destroy household, business and government budgets; and have been contributing, if not primary, factors leading to every recession over the past 40 years. It is impossible to escape the conclusion that reducing U.S. oil dependence is a critical task for the current generation of Americans.

Today, the light-duty vehicle fleet consumes more than 8.6 million barrels of oil per day—40 percent of the U.S. total. This makes the U.S. light-duty vehicle fleet not only a large part of the current problem, but also a critical part of any future solution to our reliance on petroleum.

In order to escape the severe economic consequences of oil price volatility, it is necessary to electrify the light duty vehicle segment of the ground transportation fleet. Electrification offers numerous advantages over the status quo: using electricity promotes fuel diversity; electricity is generated from a domestic portfolio of fuels; electricity prices are less volatile than oil and gasoline prices; using electricity is more efficient and has a better emissions profile than gasoline; and using electricity will facilitate reduction of greenhouse gas emissions. And, electricity is superior as a fuel for light-duty vehicles to other possible alternatives such as natural gas, hydrogen, and biofuels.

Successfully reenergizing the transportation sector is a critical task that begins with the Coalition's strategy for electrifying the light-duty vehicle fleet. This plan will not only allow the United States to achieve the President's goal of placing 1 million GEVs on the street by 2015, but will allow us to surpass it. In less than a decade, GEVs will be a proven technology representing 25 percent of new light-duty vehicle sales. The nation will be on the path to reducing oil demand in the LDV fleet by over 6 million barrels per day by 2040. Even with today's electricity generation mix, this would reduce carbon emissions in the transportation sector by 70 percent, to 601 million metric tons.

The rates of GEV adoption outlined in this Roadmap are ambitious. And with an almost ten-fold increase in the number of GEVs on the road between 2020 and 2030, the period immediately following the expiration of the recommendations in the report is

when the vast majority of the growth occurs. To achieve this growth in the level of vehicle penetration, our national commitment to electrification must remain firm. The United States must commit to, maintain focus on, and follow through with the policies outlined in this report and build on them afterwards.

While the plan outlined in this paper will be expensive, the alternatives are more so. But we cannot compare the cost of this program to current government expenditures on energy efficiency, vehicles, and advanced energy-related technology. We must, instead, compare it to the cost of doing nothing. Stated simply, the total cost of every proposal outlined in this paper is far less than the \$600 billion of costs that our dependence on oil imposed on our economy in 2008 alone as calculated by experts at the Department of Energy.

Therefore, whether oil prices rise or fall, and whether the economy falters or flourishes, the transformation of the light-duty vehicle fleet into one that derives its power from electricity is an effort that must be sustained. This continued effort will push down the cost of batteries so that GEVs are not only competitive, but are in fact less costly than vehicles with conventional internal combustion engines, thus facilitating their penetration into the vehicle market, allowing us to finally significantly reduce the threat that oil dependence imposes on our nation.

The time has come for Americans to unite behind this aggressive campaign to reduce our dependence on oil and increase domestic and national security. The proposals outlined here constitute a comprehensive and integrated plan for achieving a safer energy future for America through a decades-long endeavor. The time for action is today. We cannot waste another moment.

APPENDIX ONE

International Support for Electrification

Grid-enabled vehicles are benefiting from strong public policy support in a number of world regions. Stringent emissions targets and high fuel prices in Western Europe and Japan are promoting the manufacture of highly efficient vehicles. Energy security concerns are paramount in other countries, including China.

Electrification of transportation has been identified as a high priority by a number of governments around the world. As industry gears up to meet demand, many governments are creating initiatives to quickly expand their electrified vehicle industries. In many cases, local, national, and regional governments have signaled their commitment to electrification by instituting regulatory frameworks that transparently support GEV adoption over the long term through financial support, high gas taxes, and strong fuel efficiency rules.

To be sure, different national factors and priorities are driving the move to electrification. In some cases, the shift is derived from a need to mitigate basic energy security issues associated with oil consumption. In other cases, governments increasingly view electrification as an opportunity to abate environmental problems such as CO₂ emissions. However, perhaps the most interesting trend is that many nations—particularly in the export-oriented developing world—see early establishment of the future automotive industry as a source of national competitive advantage.

EUROPE AND ISRAEL

In the European Union, strong policies in favor of electrification first found support as a means to meet CO₂ emissions goals. The climate consensus in Europe is arguably the strongest in the world, and European governments have moved aggressively to reduce CO₂ emissions in the transport sector. From a regulatory standpoint, EU member states have committed to stringent vehicle emissions standards over the next 10 years (through 2020). By 2012, average emissions for new light-duty vehicles will need to be 120 g CO₂/km. By 2020,

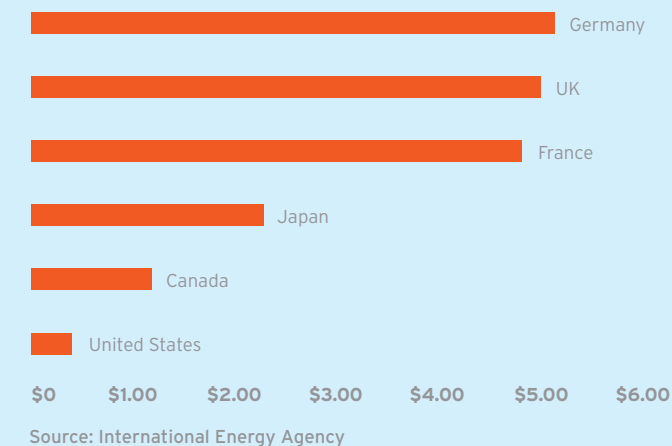
that figure falls to 95 g CO₂/km.¹ The current European light-duty fleet, mostly powered by diesel, averages 160 g CO₂/km. Many European countries believe that electric vehicles will be vital to reaching the EU targets.²

In addition, most European countries impose significant taxes on refined petroleum products like gasoline and diesel. In 2008, for example, premium unleaded gasoline prices averaged \$3.49 per gallon in the United States, compared to \$7.86 per gallon in the United Kingdom, \$7.70 per gallon in France, and \$8.13 per gallon in Germany.^{3,4} The industrial EU-wide average was \$7.85 per gallon. These comparatively high fuel prices translate into relatively higher ownership costs for a conventional vehicle versus more efficient alternatives. Higher fuel taxes, however, are just one among a number of pro-electrification policies being implemented.

Israel. Israel is an ideal candidate for electrification since it traditionally imports nearly all of its energy and considers energy supply of utmost national security importance. Moreover, the country is relatively small and is essentially an island, as driving through surrounding countries is not possible. High gas prices, currently around \$6 per gallon, short driving distances, and a relatively simple north-south highway system

1 Europa, “Commission plans legislative framework to ensure the EU meets its target for cutting CO₂ emissions from cars,” Press Release, July 2, 2007, available at www.europa.eu/rapid/pressReleasesAction.do?reference=IP/07/155&format=HTML&aged=0&language=EN&guiLanguage=en.
 2 Eubusiness, “Reducing CO₂ Emissions from Light Duty Vehicles,” (September 1, 2009), available at www.eubusiness.com/Environ/co2-cars.
 3 IEA, Energy Prices and Taxes 2Q 2009, (2009) Table 11, p.338.
 4 The European Commission requires weekly reporting of automotive diesel oil, Euro super 95 premium gasoline and leaded premium gasoline. Prices are reported to the Commission as delivered prices, and exclude rebates.

FIGURE AA AVERAGE GASOLINE TAXES PER GALLON, MARCH 2008 (USD)



make the logistics of electrification with battery-swapping very straightforward.

The government has provided strong policy support to spur the deployment of GEVs and the required supporting infrastructure. The tax rate for a new conventional vehicle is 92 percent in Israel, but the rate for an EV is set at just 10 percent through 2014, rising to 30 percent in 2015.⁵ The rate for HEVs and PHEVs is 30 percent through 2012, 45 percent in 2013, and 60 percent in 2014. As part of a partnership with Better Place (discussed below), Israel will build 500,000 electric vehicle charging stations and 200 battery swap facilities for a reported \$200 million.⁶ The goal is to deploy 10,000 to 20,000 GEVs per year, starting in 2011.⁷

Denmark. Denmark’s DONG Energy has extensive wind resources, which generate peak electricity at night.⁸ A relatively small country with ample overnight charging capacity and an environmentally concerned citizenry, Denmark was another attractive candidate for Better Place. The government taxes new vehicles at a 180 percent rate and is making electric vehicles exempt from such taxes as least through 2012.⁹

5 Fisher-Ilan, Allyn, Reuters. “Israel declares “revolution” against gas guzzlers.” (June 8, 2009). available at www.reuters.com/article/GCA-GreenBusiness/idUSTRE5573ZA20090608.
 6 Kivat, Barbara. “Israel Looks to Electric Cars,” Time, (January 20, 2008), available at www.time.com/time/world/article/0,8599,1705518,00.html.
 7 Kanellos, Michael, “Israel launches electric-car program.” (January 21, 2008). available at news.cnet.com/8301-11128_3-9854591-54.html.
 8 Renewable Energy and Transportation,” Better Place, available at www.betterplace.com/opportunity/energy/.
 9 “Copenhagen accelerates admin to showcase electric cars at COP15,” Denmark.dk, (June 3, 2009).

United Kingdom. The UK has been a leader in developing a vibrant marketplace to support electric vehicles. The city of London has the largest installed base of charge points, offers consumers 2,000 to 5,000 pounds (\$3,161 - \$7,904) in tax incentives for EV purchases, and has waived its significant road taxes and city congestion charges for those driving GEVs.¹⁰ The city also offers free parking for GEVs in some areas.¹¹ In addition to infrastructure, consumers have a surprisingly wide array of pure EV choices in the UK. They can purchase a Mitsubishi i-MiEV, a Mega City, a Citroen C1 ev’ie, a Reva G-Wiz I-iON, a Reva G-Wiz I, a GEM e4, a MyCar, a Stevens ZeCar, or a Tesla Roadster.¹² Many of these cars will largely appeal only to early adopters, but the sheer availability and proliferation of EVs in the London area demonstrate the city’s seriousness about vehicle electrification.

In April 2009, London mayor Boris Johnson declared that the city would be the “electric vehicle capital of Europe” and pledged £20 million (\$32 million) to put 100,000 EVs on London streets supported by 25,000 charge points.^{13, 14} The funds Johnson promised are about one-third the estimated cost of the project and are in addition to £250 million (\$396 million) the UK government had already set aside for electric vehicle incentives.¹⁵

Germany. Germany has been accused of being behind in the European EV race due to the initial ambivalence—and even hostility—of its domestic automakers to the concept.¹⁶ However, in August 2009, the incumbent government trumped other European nations by setting a target of 1 million EVs by 2020 and allocating €500 million (\$736 million) to achieve that

FUEL TAXES
The United States has the industrialized world’s lowest fuel taxes.

10 “An Electric Vehicle Delivery Plan for London,” Office of the Mayor of London, (May 2009). available at www.london.gov.uk/mayor/publications/2009/docs/electric-vehicles-plan.pdf.
 11 Office of the Mayor of London, “An Electric Vehicle Delivery Plan for London, (May 2009), available at www.london.gov.uk/mayor/publications/2009/docs/electric-vehicles-plan.pdf.
 12 Smith, Emma, et. al., “The best electric cars on the market,” The Times, (August 30, 2009).
 13 Jha, Alok, “100,000 Electric Cars to Hit London Streets, Pledges Mayor,” EcoWorldly (April 9, 2009), available at ecoworldly.com/2009/04/09/100000-more-electric-cars-in-london-pledges-mayor.
 14 Ibid.
 15 “Electric car projects all over Europe”, Breitbart (June 30, 2009), available at www.breitbart.com/article.php?id=upi-20090630-0927-09-4470.
 16 Hillenbrad, Thomas, “Opinion: Why Germany Lags in Electric Cars,” BusinessWeek, (April 21, 2009)

goal.¹⁷ Prior to this announcement, **Daimler** had been dabbling in several demonstration projects throughout the country, the largest in Berlin. The Berlin pilot initially installed 500 chargers and had 100 Daimler smart EDs.^{18,19} The collaboration included **RWE**, the second largest German utility, and also added **Vattenfall**, another European utility. **BMW** and **E.On**, Germany's largest utility, are installing a similar project in Munich using **Mini Es**,²⁰ and other projects are taking place in Frankfurt and the Ruhrgebiet region.

France. France has been moving aggressively toward vehicle electrification. The most notable developments have been in Paris, where the national utility, **Électricité de France (EDF)**, has been trying to encourage electrification since the 1990s, when it

DEMONSTRATIONS
Many countries in Europe and Asia have already invested in demonstrations and infrastructure for GEVs.

installed more than 200 charge points throughout the city.²¹ Paris still has an installed base of electric vehicle charger points that rivals the number in London, with plans to introduce more. In October 2008, French President Nicolas Sarkozy committed €400 million over four years to aid in the development of an electrified transportation system; in April 2009, he established a goal of 100,000 electric vehicles sold in France by 2012.²² The first planned installment of these vehicles was to be 100 EVs from **Renault** to arrive in 2010.²³

In October 2009, France made successive announcements intended to dramatically boost the efforts already underway. The Minister of Energy, Jean-Louis Borloo, committed €2.5 billion (\$3.6 billion) to speed the introduction of electric vehicles; the money is to be split among “research, subsidies, and infrastructure development.”²⁴

The largest portion of the money is allocated to the installation of 1 million charge spots over the next six years.

After announcing the allocation of funds, France unveiled a specific 14-point plan that clearly outlines requisite milestones to achieve significant electric vehicle development in the country.²⁵

The city of Paris is also in the process of trying to implement a unique project patterned after its successful bike-sharing program and car sharing programs such as ZipCar or Car2Go. The goal is to establish an EV-only car sharing service throughout the city and possibly extending to the suburbs. The project has run into financial and legal hurdles, but is still underway.²⁶ Outside of Paris, **Toyota** has partnered with EDF in Strasbourg to test 100 plug-in **Priuses**.²⁷

Spain. Spain has set an ambitious goal of 1 million EVs in the country by 2014 under the banner of the Ministry of Industry's “Project Movele.”²⁸ The five-year project has been given €235 million with test pilots being established in Seville, Madrid, and Barcelona.²⁹ Vehicle tax credits of €7,000 (\$10,299) are also available.³⁰

Austria. A coalition of partners in Austria announced in July 2009 a project dubbed “Austrian Mobile Power” that aims put 10,000 EVs on Austrian roads by 2013 and 100,000 by 2020. The partners include **Siemens AG** and **Magna International**.³¹

The Netherlands. The Netherlands has unveiled an extensive electrification plan in recent years, beginning with removing the vehicle registration tax

(€6,000) for electric vehicles.³² The tax now varies by vehicle efficiency, with the purchase of a “least green” car entailing a tax increase of €540.³³ Companies developing vehicle charging infrastructure receive a 20 percent tax cut. The Dutch government is also investing €10 million to “support the large scale, early introduction of electric mobility” and is using the funds for practical testing. Initial deployment is occurring through a public-private partnership with vehicle-manufacturer **Th!nk**, which is delivering 500 cars in 2009 to Elmonet, an importer and provider of GEVs for the Netherlands.³⁴

In July 2009, the Dutch cabinet released a €65 million action plan to promote GEVs. Among its provisions is GEV exemption from the nation's road tax. An independent panel of interdisciplinary experts has been formed to develop an electrification rollout plan that will ensure stakeholder accountability and standardized charging. Jean-Paul de Poorter, the Minister of Transport, says the government's goal is to put 200,000 GEVs on the road by 2020, though he personally believes that the Netherlands could reach 1 million by 2025.³⁵ To support this goal, the government has joined with 11 of the country's regional utility management companies to install 20,000 charging stations nationwide by 2012.³⁶

Others. **Portugal** is in the midst of installing 1,300 charging stations and has announced a partnership with **Nissan-Renault**.³⁷ **Italy** has EV pilots underway in Tuscany and Rome, with more to follow in Milan and Brescia. **Ireland** has set a target of 10 percent elec-

tric vehicle penetration (more than 250,000 vehicles) by 2020.³⁸

Another trend spreading across Europe may have a significant impact on future vehicle electrification demand: Low Emission Zones (LEZs) in many major cities. LEZs are demarcations within highly congested areas. Only vehicles with certain maximum rated emissions, designated by stickers, may enter the zones.³⁹ In some cases, higher-polluting vehicles may pay a fee to enter the zone as well. The scheme has been impactful in its roll-out in Berlin and London and has quickly spread to more than 80 cities in 10 countries.⁴⁰ The main driver behind LEZs is a push to reduce pollution caused by Europe's densely populated and congested cities. As the trend for LEZs progresses, it is reasonable to assume that their success may spur demand for even more stringent emissions levels, increasing demand for grid-enabled vehicles.

LEZs
Low Emission Zones that forbid or toll polluting vehicles are incentivizing GEV consumption in Europe.

EAST ASIA

Japan. The speed with which domestic automakers **Nissan**, **Mitsubishi**, and **Subaru** are moving forward with the development of electric vehicles has driven Japan to pursue an EV-friendly agenda. The cities of Tokyo and Yokohama have both announced partnerships and pilots with all three automakers.⁴¹ The **Toyota Electric Power Company (TEPCO)** has been exploring EVs in small-scale pilots for several years and has gathered some of the most complete consumer behavior data regarding EVs available to date.⁴² In August 2009, **Better Place** announced a pilot program in Tokyo under which a taxi company will test their battery swapping design.⁴³

17 “German government: 1 million electric cars by 2020,” USA Today, (August 19, 2009), available at www.usatoday.com/money/autos/2009-08-19-electric-germany_N.htm.

18 Ibid.

19 “50 Ladestationen für Elektroauto-Tests in Berlin,” *Stimme*, (April 27, 2009), available at www.stimme.de/suedwesten/wirtschaft/wi/Energie-Verkehr-Auto%3Bart19071,1517289.

20 “Gesucht: Testfahrer für das Elektroauto,” *Merkur*, (April 29, 2009), available at www.merkur-online.de/freizeit/gewinnspiel/gesucht-testfahrer-elektroauto-233094.html.

21 Fairley, Peter, “Deja Vu for French Plug-In Plans,” *MIT Technology Review*, (February 20, 2009).

22 Popa, Bogdan, “France to Open Charging Stations for Electric Cars,” *Autoevolution*, (February 18, 2009).

23 “Renault to test electric cars in Paris, Milan: company,” *Physorg*, (July 2, 2009).

24 Guillou, Clement, et. al., “France to invest 2.5 bln eur for electric car launch,” *Reuters*, (October 1, 2009), available at www.reuters.com/article/rbssConsumerGoodsAndRetailNews/idUSL163661420091001.

25 “Un plan national pour développer les véhicules propres,” *Ministère de l'Écologie, de l'Énergie, du Développement durable et de la Mer*, (October 2009), available at www.developpement-durable.gouv.fr/article.php3?id_article=6001.

26 Navarro, Xavier, “Paris' electric vehicle car-sharing system put on hold,” *Autoblog Green*, (April 16, 2009).

27 “EDF and Toyota announce large-scale demonstration of Plug-in Hybrid Vehicles in Strasbourg, France,” *EDF*, (March 18, 2009), available at press.edf.com/the-edf-group/press/press-releases/noeud-communiqués-et-dossier-de-presse/edf-and-toyota-announce-large-scale-demonstration-of-plug-in-hybrid-vehicles-in-strasbourg-france-601679.html.

28 Burdick, Dave, “Project Movele: Spain's Electric Car Plan,” *Huffington Post*, (March 19, 2009)

29 “Spain aims for a million electric vehicles by 2014,” *BusinessGreen*, (July 31, 2008).

30 Navarro, Xavier, “Spain announces electric vehicle rebates of up to €7,000 per car,” *Autoblog Green*, (July 10, 2009).

31 “Meilenstein für Elektromobilität in Österreich,” *Ökonews*, (July 22, 2009), available at www.oekonews.at/index.php?mdoc_id=1042004.

32 “Green Labels and Taxes for European Cars – current Situation,” *Environmental Technologies Action Plan*, (September 2006), available at ec.europa.eu/environment/etap/pdfs/sept06_car_label_taxes.pdf.

33 “Netherlands offers tax breaks for hybrid cars,” *ENDS News*, *ENDSEurope.com* (July 5, 2006), available at www.ends.europa.com/12207; “The Netherlands Efficiency Action Plan 2007,” (2007), available at www.medemp.eu/CMS/ImageUpload/eaaff26cc-49b0-4415-93a6-f844cf6ee43a.pdf.

34 “Think enters the Dutch market with a 500 unit MOU,” *Think.com* (March 18, 2009), available at www.think.no/think/Press-Material/Press-releases/Think-enters-the-Dutch-market-with-a-500-unit-MOU.

35 Evans, Chris, “Dutch Gear up for Electric Vehicles,” *Minds in Motion*, July 29, 2009, available at www.mindsinmotion.net/index.php/mimv34/themes/hybrid_electric/featured/dutch_gear_up_for_electric_vehicles, last accessed September 21, 2009.

36 “Charging Stations for Electric Vehicles,” *Radio Netherlands Worldwide*, April 24, 2009.

37 “Electric car projects all over Europe,” *Breitbart* (June 30, 2009), available at www.breitbart.com/article.php?id=upiUPI-20090630-092709-4470.

38 “Ireland Sets Goal of 10% EVs by 2020,” *Green Car Congress*, (January 30, 2009).

39 “What are LEZs?” *European Union*, available at www.lowemissionzones.eu/what-are-lezs--othermenu-32.

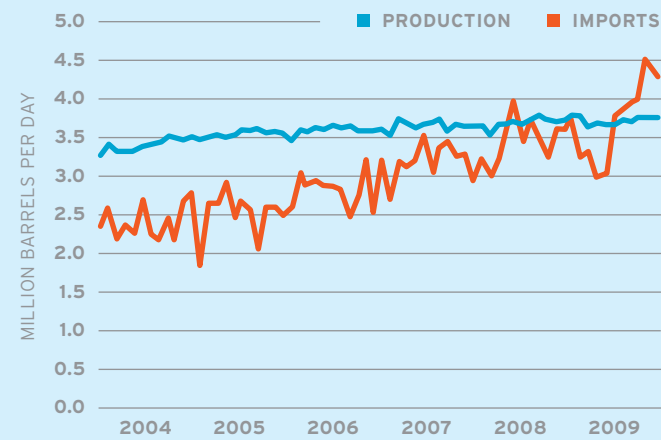
40 “Quick guide to all LEZs,” *European Union*, available at www.lowemissionzones.eu/countries-mainmenu-147.

41 O'Dell, John, “Japanese Companies to Gather Data on EV Drivers' Use of Rapid Chargers,” *Green Car Advisor*, (August 13, 2009), available at blogs.edmunds.com/greencaradvisor/2009/08/japanese-companies-to-gather-data-on-ev-drivers-use-of-rapid-chargers.html.

42 “‘Range Anxiety’ not Based on Rational Thinking,” *Autoblog Green*, (August 25, 2009), available at green.autoblog.com/2009/08/25/study-range-anxiety-not-based-on-rational-thinking/.

43 “Better Place Targets Tokyo Taxis for Battery Switch Application,” *Better Place*, (August 26, 2009), available at www.betterplace.com/company/press-release-detail/better-place-targets-tokyo-taxis-for-battery-switch-application/.

FIGURE AB CHINESE OIL IMPORTS, MONTHLY



Source: ARC Financial; Bloomkberg; EIA

China. Developments in China are of special note. Chinese leaders have identified electrification as a high strategic priority on two fronts. First, domestic deployment of GEVs is a relatively straightforward energy security strategy. As the Chinese economy has rapidly expanded over the past several years, oil consumption has increased as well. Between 2000 and 2009, annual oil demand grew at an average rate of 6.7 percent.⁴⁴ Domestic Chinese oil production, meanwhile, has remained relatively flat, leaving the gap to be filled by increasingly substantial oil imports. Between January 2004 and September 2009, Chinese oil imports grew by 80 percent.

The key driver in rising Chinese oil demand, and therefore imports, has been the transportation sector. In 2007, the International Energy Agency forecast that annual light-duty vehicle sales in China would surpass those of the United States in 2016.⁴⁵ In fact, it now appears that China accomplished this feat in 2009. Total light-duty vehicles sales through the first three quarters in China were 9.6 million compared to 7.8 million in the United States.⁴⁶ Importantly, the growth in Chinese auto sales is forecast to continue for decades. In 2008, there were 65 million registered vehicles in China.⁴⁷ This figure is expected to reach approximately 150 million in 2020 and nearly 230 million by 2030.⁴⁸

44 BP plc, *Statistical Review of World Energy 2009*, p. 12; SAFE calculations

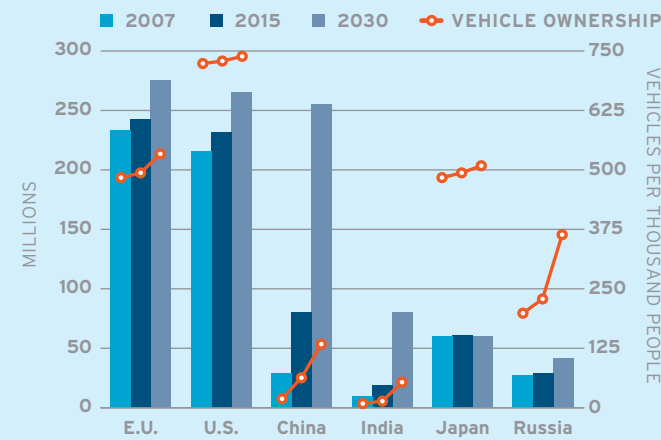
45 IEA, *World Energy Outlook 2007*, p.300.

46 "China outracing U.S. in vehicle sales," *Associated Press*, October 14, 2009.

47 IEA, *World Energy Outlook 2008*, p. 100.

48 Id.

FIGURE AC LIGHT-DUTY VEHICLE STOCK BY REGION, HISTORICAL AND FORECAST*



Source: International Energy Agency

* IEA estimates for passenger light-duty vehicles only.

The projected impact of this growth in vehicle ownership will depend heavily on technology. According to the IEA, based on existing technology and policies, over the coming decades roughly two-thirds of global oil demand growth will occur in China and India. Of the total increase of 21.2 mbd in the IEA reference scenario, nearly one-third will occur in the Chinese transport sector alone.⁴⁹ If grid-enabled vehicles and other efficient technologies are deployed in high concentrations, the growth in Chinese oil demand clearly could be curbed, and the need for ever-higher quantities of imported oil could be mitigated.

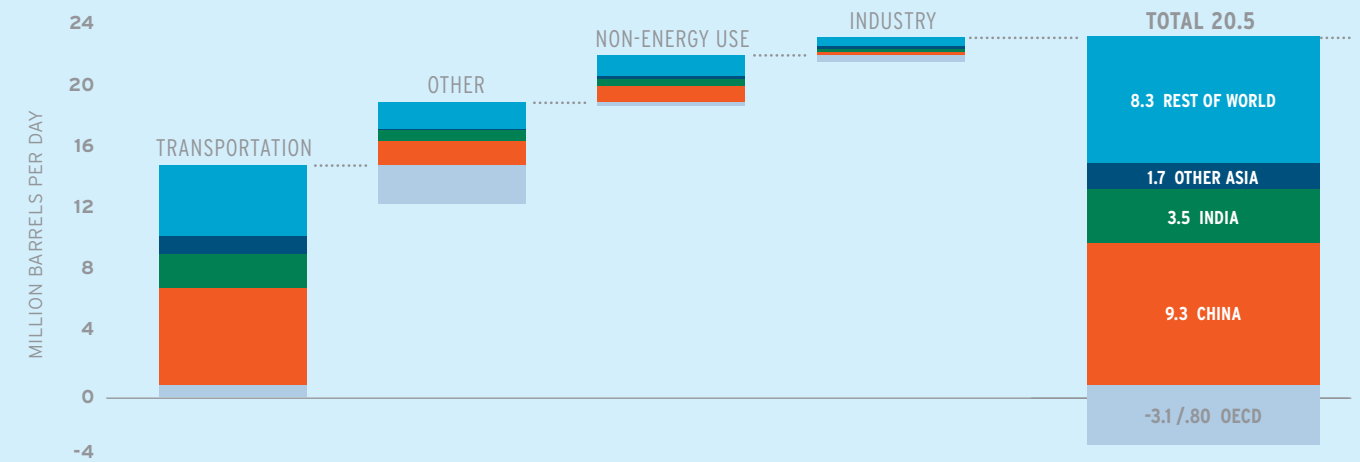
In addition to energy security concerns, Chinese leadership is also dealing with very tangible consequences of urban pollution. Many cities are already grappling with the effects of high concentrations of air pollution, and China can hardly afford to add nearly 200 million conventional vehicles to its fleet over the next 20 years. Thus China has also identified electrification as a critical environmental sustainability measure that will support future economic growth by providing access to energy in the transport sector.

Perhaps most important from a U.S. perspective, Chinese political leadership has targeted electric vehicle manufacturing as a strategic industry that will allow it to maintain its global manufacturing dominance.⁵⁰ China views grid-enabled vehicles as an opportunity to

49 IEA, *WEO*, p.98.

50 "A new era: Accelerating toward 2020 —An automotive industry transformed," *Deloitte*, available at www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/A%20New%20Era_Online_final.pdf.

FIGURE AD INCREMENTAL OIL DEMAND BY SECTOR, 2006-2030



Source: International Energy Agency

vault their foreign rivals, especially considering that a dominant share of global lithium-ion battery production already takes place in the country. Although the Chinese government is working to develop a domestic EV market, it is becoming clear that the major Chinese automotive firms have their long-term sights planted firmly on the export market.

At an industry conference in Tianjin in early September 2009, Minister of Science and Technology Wan Gang said that given China's large lithium deposits and extensive battery-manufacturing experience, GEVs are a strategic area of interest, and as a "key driver for a new economy" will be an opportunity for China to "catch up with and exceed developed countries."⁵¹

China has supported its electrification strategy with credible, long-term public support. In 2009, the central government began an initiative to develop sufficient electric vehicle infrastructure for large scale deployment in the country's largest 13 cities.⁵² Wuhan, a city of more than 9 million people, will be the lead city in the project. Wuhan is working with **Nissan** to develop the infrastructure, and the automaker will provide the

city with 600 EVs at no cost.⁵³ This will be followed with infrastructure investments over the succeeding four years in the cities of Shanghai, Beijing, Shenzhen, Chongqing, Hangzhou, Jinan, Dalian, Kunming, Changsha, Nanchang, Changchun, and Hefei, which range in population from 1.1 million to 17 million people.⁵⁴ The government's goal is to have installed capacity to produce 500,000 grid-enabled vehicles by 2011.⁵⁵

These initiatives are naturally supported by government funding. Ten billion yuan (\$1.5 billion) has been set aside to nurture research and development.⁵⁶ The government is also offering a 60,000 yuan (\$8,791) per-vehicle incentive and a 500,000 yuan (\$73,255) incentive on bus purchases.⁵⁷ China has provided battery and GEV companies with generous low-interest loans from state banks and has a multi-year technology development program on which it spent \$161 million between 2006 and 2008. The **State Grid**, a state-owned company that controls most electric transmission lines, is planning the construction of charging infrastructure.⁵⁸

53 Shirouzo, Norihiko, "China Sets Electric-Car Plan," *The Wall Street Journal*, (April 9, 2009).

54 Id.

55 Shirouzo (2009).

56 Xinlian, Liu, "In the Name of Green," *Beijing Review*, (May 17, 2009).

57 Shimizu, Naoshige. "China to Push Green Cars; India to Focus on EVs," *Tech-On*, (May 28, 2009), available at techon.nikkeibp.co.jp/english/NEWS_EN/20090525/170620/.

58 Synergistics, "China's Next Revolution: Leading the Transition to Electric Cars," Presentation at the European Union Chamber of Commerce, July 2, 2009, available at www.slideshare.net/wruso101/china-leading-the-transition-to-electric-cars, last accessed September 22, 2009.

51 *Renewable Energy Magazine*, "Head of one of China's leading electric vehicle manufacturers urges China to do more to promote electric and other "new energy" vehicles," September 9, 2009, available at www.renewableenergymagazine.com/paginas/ContenidoSecciones.asp?ID=14&Cod=4055&Nombre=RSS, last accessed September 22, 2009.

52 "Renault-Nissan Alliance Partners with China Ministry of Industry and Information Technology on EVs," *Green Car Congress*, (April 10, 2009), available at www.greencarcongress.com/2009/04/renaultnissan-alliance-partners-with-china-ministry-of-industry-and-information-technology-on-evs.html#more.

APPENDIX TWO

State of the Global GEV Industry

With battery technology advancing and firm public policy support in place in many countries, 2009 witnessed a sharp increase in GEV activity globally. High and volatile global oil prices in 2007 and 2008 probably also played a role in spurring consumer interest, but should not be counted on over the long term.

As a result of high oil prices and a growing emphasis on curbing CO₂ emissions, the year 2009 has seen an unprecedented surge in world-wide interest and announcements regarding vehicle electrification. This wave was arguably triggered in 2006 with the unveiling of the Tesla Roadster, a niche electric performance sports car that turned the traditional notion of EVs as ‘dinky’ city cars upside down. The introduction of General Motors’ Volt concept the next year added credence to the idea that electrification was becoming possible. Both of these vehicles captured the public’s attention, adding a cachet that GEVs previously did not possess.

BetterPlace’s announcements in 2008 that it would partner with Nissan-Renault and establish extensive electric vehicle charging networks throughout Israel and Denmark made it seem, for the first time, that vehicles and infrastructure were arriving together. Prior to 2009, there had been noteworthy announcements of electric vehicle infrastructure installations in only eight countries. But in 2009 alone, 22 countries have declared that they are setting up infrastructure and vehicle networks, with multiple announcements coming from many countries in Western Europe, East Asia, and the United States. Buoyed by these regional announcements, global automakers have become increasingly committed to introducing grid-enabled vehicles. Although the industry’s focus is far from centered on electrification, the current era of rapid GEV promises is unprecedented in the automobile age.

NORTH AMERICAN AUTOMOTIVE OEMS

General Motors. GM’s Chevy Volt was the first plug-in vehicle promised by a major automaker.⁵⁹ GM’s strategy for a return to success has in part been based on its high-profile Volt introduction, as well as successive versions of vehicles based on the Voltec platform, on which the Volt is based.⁶⁰

The Volt is an evolution of the plug-in hybrid concept. Whereas the Ford or Toyota versions of the plug-in hybrid can be powered by either their electric motor or their gas engine, GM’s Voltec drivetrain only powers the wheels through the electric motor. After the battery reaches the end of its charge depleting mode, which is specified to be approximately 40 miles, the conventional internal combustion engine will start up and act as a generator to maintain the battery charge level, allowing the down-sized engine to continuously operate at peak efficiency.⁶¹

During the initial charge depleting mode, the Volt burns no gasoline at any speed. Rather, it runs only on electricity. The vehicle does not begin to use gasoline until after the battery has reached the minimum state of charge. To highlight this distinction from other

59 Stewart, Ben. “GM Testing Volt’s Battery, iPhone-like Dash on Track to 2010,” *Popular Mechanics*, (April 4, 2008), available at www.popularmechanics.com/automotive/new_cars/4257460.html, last accessed on October 23, 2009.

60 “GM Plans to Unveil Several New Voltec Electric Car Concepts Throughout 2009,” *GM Volt Website*, (February 9, 2009), available at gm-volt.com/2009/02/09/gm-plans-to-unveil-several-new-voltec-electric-car-concepts-throughout-2009/, last accessed on October 23, 2009.

61 Voelcker, John. “Why is the 2011 Chevrolet Volt NOT a Hybrid?” *Green Car Reports*, (August 20, 2009), available at www.greencarreports.com/blog/1034474-why-is-the-2011-chevrolet-volt-not-a-hybrid, last accessed on October 23, 2009.

plug-in hybrids, GM has dubbed the Volt an extended range electric vehicle, or E-REV.⁶² The company characterizes the IC engine as a “range extender” that is used to extend the range of the vehicle past the 40 mile electric-only range.

Ford Motor Company. Ford has produced a line of well-received hybrid models as well as other fuel saving technologies such as EcoBoost. Though it has been testing plug-in hybrid Ford Escapes for several years with utility partners, Ford first promised to introduce commercial PHEV volumes when it appeared with the other Detroit automakers before Congress in 2008 to present their restructuring plans.⁶³

Ford’s restructuring promised a total of three plug-in vehicles to arrive in rapid succession from 2010 to 2012.⁶⁴ First, it will sell a fully electric version of its small utility van—dubbed the Transit Connect—in 2010. The following year, it will begin offering an electric version of its popular Focus sedan. In 2012, Ford will utilize the plug-in hybrid technology being tested in the Escape to offer a new as-yet unnamed plug-in hybrid SUV. Ford’s current demonstration fleet of Escape PHEVs is using lithium-ion batteries supplied by **Johnson Controls-Saft**. Early in 2009, Ford announced a partnership with Johnson Controls-Saft to produce lithium-ion batteries for Ford’s emerging commercial PHEV models.

The Transit Connect EV will be produced in partnership with **Azure Dynamics** and Johnson Controls-Saft and will go on sale in 2010. Azure Dynamics has engineering and assembly facilities located in Michigan, Massachusetts, and Vancouver B.C.⁶⁵ The firm has begun work on an assembly plant in St. Louis. The Focus EV will use an electric drivetrain that was developed and integrated by **Magna International**, a large Tier 1 supplier. By utilizing Magna’s technology, Ford hopes to speed its EV to market faster than if it

were to develop the powertrain components itself, as is traditionally the practice.

The June 2009 DOE loan awards included \$550 million for Ford to retool their Michigan Assembly Plant to produce the Focus EV.⁶⁶

Chrysler. Chrysler has promised a slate of grid-enabled vehicles through 2014 and has unveiled a suite of EV and E-REV concepts at auto shows throughout the country.⁶⁷ In the restructuring plan presented to Congress, Chrysler unveiled

plans to introduce an EV roadster in 2010 followed by a Fiat-based city car EV in 2011.⁶⁸ The next three years would see subsequent introductions of two Fiat-based SUV E-REVs and two multi-purpose vehicle E-REVs. However, post-bankruptcy, Chrysler has neither publicly confirmed nor changed this plan other than to announce a close battery supply arrangement with A123.⁶⁹

GEVs IN 2009
2009 has seen a flurry of new GEV announcements, including new vehicle lines and government initiatives.

EAST ASIAN AUTOMOTIVE OEMS

Nissan-Renault. Nissan-Renault is introducing five models of pure electric vehicles over the next several model years, and the company has publicly supported EVs as the future of transportation.⁷⁰ The conglomerate’s first production vehicle will be the Nissan LEAF EV, available in limited volumes beginning in 2010 and reaching mass production in 2012. Nissan has prom-

66 “Ford Investing \$550M to Retool SUV Plant to Produce Focus Small Car and EV,” *Green Car Congress*, (May 6, 2009), available at www.greencarcongress.com/electric_battery/, last accessed on October 23, 2009.

67 Doggett, Scott. “Chrysler Says It Will Offer Three Electric-Powertrain Models Within 3-5 Years,” *Green Car Advisor*, (June 14, 2008), available at blogs.edmunds.com/greencaradvisor/FuelsTechnologies/FuelCell/, last accessed on October 22, 2009.

68 “Chrysler Plans To Sell Nine Fiat-Based Vehicles by 2014,” *Edmunds Inside Line*, (February 19, 2009), available at www.edmunds.com/insideline/do/News/articleId=142367, last accessed on October 22, 2009.

69 “A123 leads charge for Chrysler EV,” *Boston Herald*, (April 7, 2009), available at www.bostonherald.com/business/automotive/view/2009_04_07_A123_leads_charge_for_Chrysler_EV/srvc=business&position=also, last accessed on October 22, 2009.

70 Chilcote, Ryan, and Laurence Frost. “Renault’s Ghosn Says Future of Electric Autos Hinges on \$70 Oil,” *Bloomberg*, (September 16, 2009), available at www.bloomberg.com/apps/news?pid=20601109&sid=aR2eQwSe7_S8, last accessed on October 22, 2009.

62 Id.

63 “Ford Motor Company Submits Business Plan to Congress,” *Ford Motor Company*, (December 2, 2008), available at www.ford.com/about-ford/news-announcements/press-releases/press-releases-detail/pr-ford-motor-company-submits-29508, last accessed on October 23, 2009.

64 “Ford Rolls Out Accelerated Plan for HEVs, PHEVs and BEVs; To Partner with Magna on BEVs, First One Due in 2011,” *Green Car Congress*, (January 11, 2009), available at www.greencarcongress.com/2009/01/ford-rolls-out.html, last accessed on October 23, 2009.

65 Smith Electric Vehicles, “Why Smith: World’s Largest Manufacturer,” available at www.smithelectricvehicles.com/whysmith_largestmanu.asp, last accessed on October 23, 2009.

ised that the vehicle will be priced competitively with traditional internal combustion vehicles.⁷¹

In June 2009, the automaker was one of three recipients of DOE loans to develop domestic capacity to produce the LEAF. Nissan directed \$550 million of the \$1.6 billion award towards retooling its Smyrna, TN vehicle assembly plant and used \$1.05 billion to construct an adjacent battery assembly facility.⁷² In September 2009, Renault unveiled four concept full-electric vehicles and promised to have production versions ready and on the road within two years.⁷³ Notable among these is the Fluence ZE, which features a swappable battery compatible with the **Better Place** system, discussed later in this appendix.⁷⁴

Realizing the fundamental problem of consumer EV acceptance without supporting infrastructure, Nissan has established partnerships with municipalities around the world to develop the supporting infrastructure that their vehicles will require. Many of these agreements are focused, well-defined, government-sponsored installation projects. However, outside of the specific regions where the automaker has partnered with Better Place, none of these installations is likely to be sufficient to accommodate broad scale adoption of electric vehicles.

BETTER PLACE
Nissan-Renault, and Better Place have partnered in a number of countries to provide vehicles and infrastructure.

An example of Nissan's installation projects would be the recent five-city infrastructure development grant the firm received (in cooperation with **ECotality**) from the Department of Energy. These projects will

place up to 1,000 vehicles and just over 2,000 charge points in cities throughout five U.S. regions.⁷⁵

Toyota. Toyota has aggressively invested in traditional hybrid technology, and the company is taking a cautious footing regarding GEVs. Early in 2009, Toyota announced a plug-in Prius program which would up-size the Prius' standard battery pack and add a plug.⁷⁶ Five hundred of these plug-in Priuses are already being made available internationally in test fleets, with expected market introduction in 2012.⁷⁷ Additionally, Toyota has promised the introduction of a small city EV by 2012 and has been showing concepts such as the iQ in Frankfurt and the FT-EV II in Tokyo in 2009.⁷⁸ Concurrent with these vehicle pronouncements, though, Toyota representatives, particularly in the United States, have objected to the notion that plug-in vehicles are ready for the mass market.⁷⁹

Honda. Honda is a market leader in efficient internal combustion engines and had used a large portion of its research dollars on fuel cells. In recent months, the company has made announcements regarding an electric vehicle introduction some time before 2015.⁸⁰ However, no details or specifications are yet available of the expected mini-car class vehicle, with the only hint at the development process coming in the form of

the EV-N concept unveiled in a preview to the Tokyo Auto Show in September 2009.⁸¹

Mitsubishi. 2009 marked the introduction of the Mitsubishi's diminutive four-seater i-MiEV.⁸² Although not yet available in the United States, early demand for the i-MiEV has surpassed Mitsubishi's expectations and the carmaker has twice announced capacity increases to meet that demand, raising its target to more than 30,000 annual production units by 2013.⁸³ Concerns have surfaced regarding the vehicle's exorbitant price, but company executives have promised to cut the price in half—to around \$20,000—by mid-2010, when production begins to ramp up.⁸⁴ Mitsubishi is also reported to have several other electric models, including a plug-in hybrid, on the way.⁸⁵

Subaru. Subaru is currently offering a Stella electric vehicle in Japan that debuted around the same time as the Mitsubishi i-MiEV.⁸⁶

Hyundai. Hyundai has recently made a push to radically 'green' their line-up. As part of that effort, the company announced its intention to sell a plug-in hybrid in the United States in 2012.⁸⁷

BYD. In total, China now boasts 40 automotive companies working on electric vehicle programs.⁸⁸ Many

of these firms showed production-ready electric vehicles during the 2009 Shanghai Auto Show. The firm that has captured the most global attention, however, is BYD, originally a battery maker that has vertically integrated into vehicle production.

BYD's tenability was given a dramatic boost in 2008 with the announcement that investor Warren Buffet had taken a stake in the company.⁸⁹ In September 2009, Buffet announced that he would be increasing his share.⁹⁰ In 2009, BYD also announced a battery supply deal with **Volkswagen**.⁹¹

BYD has beaten all American automakers to market with a commercially available plug-in hybrid, currently being sold in China. The company announced in August 2009 that it would aggressively enter the U.S. market with the F3DM PHEV in 2010, earlier than originally planned, and will follow up with a full slate of grid-enabled vehicles.⁹²

Not receiving as much attention, but potentially an even larger development in China's race to vehicle electrification, is the announcement that the country's 10 largest automakers have banded together in an EV coalition, called T10, designed to rapidly spur research and development while driving down the costs of implementation.⁹³ The 10 companies involved in the effort are **SAIC Motor, FAW Group, Dongfeng Motor, Changan Auto, Guangzhou Auto, Beijing Auto, Brilliance Auto, Chery Auto, Sinotruk Group and Jianghuai Auto**.⁹⁴

BYD USA?
Within a few years Chinese companies, led by BYD, will likely enter the U.S. EV market.

71 "Nissan unveils a zero-emissions affordable electric car called the Leaf set to go on sale next year," NY Daily News, (August 3, 2009), available at www.nydailynews.com/money/2009/08/03/2009-08-03_nissan_unveils_an_affordable_electric_car_called_the_leaf_set_to_go_on_sale_in_2.html, last accessed on October 22, 2009.

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EUROPEAN AUTOMOTIVE OEMS

The German automakers as a whole have been slow to begin electric vehicle programs. They have invested heavily in clean diesel in recent decades and have generally seemed to prefer incremental improvements on existing technologies as a path to meet European regulation for reduced emissions. However, recent developments have indicated that this trend may be changing with a push towards vehicle electrification.

The Frankfurt Auto Show in September 2009, the largest auto show in the world, was somewhat of a coming out party for European automakers and EVs. The theme of the auto show, as reported by the preponderance of media outlets, was the electrification of the automobile.^{95, 96} European firms Renault, Mercedes, BMW, Volkswagen, and Audi all unveiled new plug-in vehicle concept or production cars.

Daimler. Daimler has spent a large share of its research budget on fuel cell development. The company's previous GEV experiments have been relegated to its down-market Smart Brand. The Smart ED has been delivered in small quantities for pilot programs in London and Berlin.⁹⁷ The second generation of the Smart ED will reportedly use lithium-ion batteries borrowed from Tesla Motors and will begin small-scale production in late 2009. The vehicle is still not being produced for commercial sale,⁹⁸ but is expected to be available to consumers by 2012.⁹⁹ The automaker has announced a large investment in a Hambach, France manufacturing facility to prepare for commercial production by that date.¹⁰⁰

In May 2009, Daimler acquired a 10 percent stake¹⁰¹ in upstart EV automaker **Tesla Motors** for \$50

million.¹⁰² The agreement stated that Daimler would provide Tesla with manufacturing and design expertise, and Daimler would utilize Tesla's experience in battery pack adaptation.

In September 2009, Mercedes debuted a nearly production-ready version of a GEV concept shown eight months earlier in Detroit, but timing of the vehicle's introduction remains unclear. The vehicle is based on the existing small A-class platform.¹⁰³

BMW. After long sticking with hydrogen as the future power source for its vehicles, BMW made a sharp reversal in 2009 when it announced a 500-vehicle American pilot in the U.S. of its Mini E electric vehicle.¹⁰⁴ BMW required potential customers of the electric Minis, which were distributed in California and New York/New Jersey, to apply to be a part of the program and to sign an \$800 per month two-year lease.¹⁰⁵ Lacking a previous focus on EVs, BMW purchased the electric drivetrains for the Mini E project from an American firm **AC Propulsion**. The Mini E project has since been expanded to London, Munich, and France.¹⁰⁶

In August 2009, BMW announced that it would establish a sub-brand designation of "i" for its full range of environmentally friendly cars, similar to the "M" designation for their performance vehicles.¹⁰⁷ The first of these will be a four-seat city EV. As recently as May 2009, the vehicle was set to debut in 2015.¹⁰⁸ However, sensing that it was falling behind in the race to produce electric vehicles, BMW has since moved that date forward to 2012.¹⁰⁹

Volkswagen. A primary producer of small and efficient diesel vehicles, VW has been the most strident German automaker in regards to its opposition to electric vehicles. And yet, in the marketplace, the carmaker seems to be pursuing a bifurcated approach. In March 2009, VW's top executives were quoted publicly panning the viability of electric vehicle. CEO Martin Winterkorn claimed that EVs are at least 15 to 20 years away.¹¹⁰ Later, VW of America CEO Stefan Jacoby suggested it would be 35 years before electric vehicles would gain any noticeable share of the market.¹¹¹

Just four months later—in July 2009—Winterkorn announced that VW would begin selling an electric vehicle based on its up! concept in 2013.¹¹² The CEO was, however, notably cautious when announcing the vehicle, emphasizing that electrification is still far away and that consumers should not be caught up in "electro-hype."¹¹³ VW's subsidiary Audi is also planning an electric vehicle introduction, even earlier than the parent company. The Audi E1 will be an electric version of the A1, also based on the VW up! concept, and is scheduled to appear in 2011.¹¹⁴ A revival of the Audi A2 nameplate will also feature an optional electric powertrain and will follow the introduction of the E1.¹¹⁵ In September 2009, Audi showed a concept high-performance electric sports car dubbed the e-tron, and weeks later the automaker confirmed that it would be put into production.¹¹⁶

Volvo. Volvo has started to quietly pursue vehicle electrification, revealing plans to sell a plug-in hybrid diesel version of its new C30 in 2012,¹¹⁷ and has been public with its consideration of adding a pure electric

option to the same vehicle.¹¹⁸ The company has committed to translating its unique focus on safety to the electric vehicle.¹¹⁹

VEHICLE START-UPS AND INNOVATORS

As the notion of impending electric vehicles has become widely accepted, a number of new, small automakers have quickly appeared. Their efforts are in large part supported by the relative simplicity of a basic electric vehicle design compared to the outright complexity of an internal combustion engine and transmission.

Tesla Motors. Tesla has dominated media coverage (and consumer awareness) of EVs since its founding in 2007. Since beginning deliveries of the Tesla Roadster in 2008, the company has sold more than 500 of the cars, which start at \$108,000.¹²⁰ From its founding, the company's strategic goal has been to sell a high-end premium sports car and use the cash generated from that high-priced product to fund development of a full range of pure electric vehicles. The first follow-up vehicle to the Roadster will be the Model S sedan, expected in 2013.¹²¹

A cash infusion from **Daimler** in May 2009, and another larger investment in September 2009 by a group of investors, again including Daimler, helped solidify Tesla's financial footing.^{122, 123} If it continues to thrive, Tesla would be the first successful American start-up

GEVS IN EUROPE
Some European automakers that have traditionally focused on hydrogen or clean diesel now have EV programs.

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car company in more than 85 years.¹²⁴ Uniquely in the automotive industry, Tesla has decided not to franchise dealerships, but to own all dealers, thereby controlling the entire consumer experience.

Th!nk Global. Th!nk Global has a relatively long history in the grid-enabled vehicle space. After more than 10 years as a start-up, **Ford** purchased Th!nk Global

LI-ION MARKET
The market for lithium-ion vehicle batteries may reach \$30 billion in 2020, up from almost zero today.

(formerly PIVCO) in 1999, and the company produced more than 1,000 electric vehicles that year, making it one of the biggest players in GEV manufacturing.¹²⁵ After being spun-off in 2004 to European investors, the company struggled until re-emerging in 2004 to design the Th!nk City car.¹²⁶ In 2007, the first City EVs began rolling off the assembly line in Norway, but the automaker again found itself in financial distress at the end of 2008. After settling its debts in August 2009, the now Norwegian-owned company is manufacturing a new generation of the Th!nk City car, a compact two-door sedan with a 100 km range and a top speed of 100 km/h.¹²⁷

Fisker Automotive. Helmed by Henrik Fisker, a former designer at BMW and design director at Aston Martin, Fisker Automotive is one of a rare breed of start-ups choosing to develop a plug-in hybrid electric vehicle rather than a pure EV. The company is leading with a performance sports car, the Fisker Karma, which is due in 2010. In October 2009, Fisker announced it would spend \$18 million for a former General Motors assembly plant in Wilmington, Delaware, and spend an additional \$175 million over the next three years to refurbish and retool the factory for the production of plug-in hybrid vehicles. Funding for the deal will come from a conditional loan of \$528 million from DOE. Company officials said the plant would assemble

as many as 100,000 of the cars each year and employ about 1,500 workers.¹²⁸

Coda Automotive. Coda's plan is to import electric vehicles from a Chinese manufacturing partner and begin selling them in California in 2010.¹²⁹ The firm is lent validity from its high-profile board of directors and advisors, which includes several former Goldman Sachs executives such as Kevin Czinger, Steven Heller, and former Secretary of Treasury Henry Paulson.¹³⁰

Bright Automotive. Bright Automotive has taken a different approach than Coda, choosing to manufacture its vehicles in the United States. Bright has focused squarely on the fleet market, developing the Bright IDEA, a PHEV delivery van that is expected to ship in 2012, depending on the availability of Department of Energy loans.¹³¹

NORTH AMERICAN BATTERY OEMS

The key to making electric vehicles for the mass market is the development of a cost-effective, high energy battery. The earliest EVs used batteries with lead acid and nickel metal hydride chemistries, neither of which have especially good energy density. Energy density—the measure of how much energy capacity the battery has versus its weight—is the key characteristic that determines the electric-only driving range of any grid-enabled vehicle, a primary attribute for consumer acceptance.

Current state-of-the-art battery chemistry—and the vast majority of research and development money for large format batteries appropriate for electric vehicles—is based on lithium-ion. In fact, it is likely that worldwide investment in lithium-ion battery production will result in over-capacity through 2013. The transportation sector has been forecasted to grow from essentially no lithium-ion battery demand in 2009 to more than \$30 billion in demand by 2020, as lithium-

ion becomes the dominant battery base chemistry for not only grid-enabled vehicles, but also traditional hybrid-electric vehicles as well.¹³²

As battery manufacturing has grown up with the consumer electronic industry in Asian countries, American lithium-ion battery manufacturing has been relegated inconsequential. In an effort to reclaim a leadership role, the Department of Energy announced grants in August 2009 to spur emerging leading domestic battery manufacturers.¹³³

Johnson Controls. Johnson Controls was the single largest DOE grant recipient of nearly \$300M for domestic advanced battery manufacturing and infrastructure development. As noted earlier, through its joint venture with Saft, Johnson Controls-Saft has been a long-time development partner on Ford's demonstration fleets and will supply the lithium-ion battery system for Ford's PHEV production program. They are the supplier for the previously discussed Mercedes S400 BlueHybrid, the first vehicle brought to market with a lithium-ion battery. Their technology will be subsequently introduced in late 2009 for BMW, in addition to other commercial vehicle programs. Their first U.S. manufacturing plant will come on-line next year to support Ford, Azure Dynamics, and Daimler.¹³⁴

A123 Systems. A123, a spin-off from an MIT research project, received \$249 million to establish battery production in the United States.¹³⁵ To date, the company's battery assembly facilities have been located in Asia.¹³⁶ A123 has been announced as the strategic battery supplier for **Chrysler** and has also been consistently in the running to develop batteries for **GM's** forthcoming grid-

enabled vehicles.^{137, 138} The firm's initial public offering in September 2009 was an immediate success, with share prices doubling on the first day of trading.¹³⁹ The offering was heralded as a bellwether for clean energy stocks in a rebounding economy.¹⁴⁰

Others: Dow Kokam is a joint venture between Dow Chemical Company and Townsend Kokam to produce lithium-polymer batteries.¹⁴¹ **Compact Power**, the domestic division of parent LG Chem, was chosen to produce the first generation of batteries for the Chevrolet Volt.¹⁴² **EnerDel** is a battery manufacturer in Indiana that is aggressively increasing capacity and has been announced as the supplier for Think Automotive.¹⁴³

EAST ASIAN BATTERY OEMS

Today's lithium-ion battery market is dominated by consumer electronics applications, and two major players supply nearly half of all production: **Panasonic** and **Samsung**.¹⁴⁴ Both of these manufacturers are based in Asia, as is over 88 percent of all lithium-ion battery production.¹⁴⁵ The main hubs for battery production are Japan, China, and South Korea.¹⁴⁶

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Although producers of batteries for consumer electronics typically develop and sell their products without any outside partnerships, the emerging landscape for large-scale automotive batteries is markedly different: nearly every major battery manufacturer has established some sort of joint venture or partnership with either an automotive OEM or one of their Tier 1 suppliers.

Panasonic. Panasonic has developed a joint venture with **Toyota** to produce that automaker's batteries for all electrified applications.¹⁴⁷

Samsung. Samsung has entered into a battery production joint venture with **Bosch**, one of the largest automotive suppliers in the world, to create **SB LiMotive**.¹⁴⁸

NEC. NEC has joined with **Nissan** in a joint venture called **AESC**.¹⁴⁹

BYD. Unique among the battery manufacturers is China-based BYD (previously discussed on page 163). Whereas most automotive OEMs are clearly signaling that they believe a secured supply of lithium-ion batteries is of strategic importance and have formed partnerships up the value chain to secure that supply, BYD has taken the opposite approach. The firm began as a battery manufacturer and has since moved downstream into automotive production.

EUROPEAN BATTERY OEMS

Evonik. Evonik has joined with **Daimler** to establish a joint venture called **Li-Tec Battery**.

INFRASTRUCTURE

Of course, as automakers begin to roll out grid-enabled vehicles, they will be dependent on an entirely new industry to ensure that the infrastructure to support the vehicles is ready. A new landscape of charge point manufacturers and operators is quickly developing,

yet already a few notable firms have solidified their place in this emerging field.

NORTH AMERICAN INFRASTRUCTURE PROVIDERS

Better Place. Better Place aims to be a complete end-to-end provider of the electric mobility experience for consumers. The company envisions dense urban clusters of pure EVs blanketed by charge spots in front of homes, offices, shopping centers, and anywhere vehicles pause.¹⁵⁰ Along major arteries connecting cities, Better Place proposes to construct battery replacement stations that can remove a depleted battery and replace it with a fully charged unit in less time than a typical gasoline fill-up.¹⁵¹

As a network operator, Better Place's interaction with consumers would closely resemble the mobile phone model. It intends for consumers to purchase their car as normal, but Better Place will own the vehicle battery and provide the electricity for charging. Similar to buying cell phone minutes, consumers will buy miles from Better Place.¹⁵² Drivers who accumulate enough miles may even have their vehicle purchase subsidized by Better Place, just as mobile phone providers subsidize customers' hardware purchases today.

The Better Place strategy attempts to identify the barriers to consumer adoption of EVs and integrate solutions into their business model that remove each of those barriers. Consumers fear being stuck with a depleted battery, and Better Place will provide ample refueling infrastructure and the occasional battery swap to alleviate this. Consumers fear being saddled with expensive batteries that underperform or are obsolete, and Better Place, by assuming ownership of the batteries, has eliminated the concern. Finally, to counter claims that EVs simply shift carbon emissions from the tailpipe to dirty coal-powered plants, Better Place has committed to purchasing electricity exclusively from renewable sources.

There are many skeptics of Better Place's business model, most notably surrounding the feasibility of battery swapping, which could require automakers

to standardize battery formats across vehicle platforms and manufacturers.¹⁵³ Better Place must also be invested in extra (expensive) battery capacity. Better Place claims to have sufficiently answered their detractors, and its business model will soon be put to the test—it is rolling out its taxi demonstration project in Japan¹⁵⁴ and complete systems in Israel and Denmark that should be online by 2012.¹⁵⁵

ECotality. ECotality's heritage in the EV charging industry comes from a history of developing fast-charging systems for industrial material handling under the eTec brand.¹⁵⁶ The company has utilized that experience in developing charge point equipment for EVs. **Nissan** had already announced a partnership with eTec to develop recharging infrastructure stretching from Phoenix to Tucson, AZ when DOE awarded grant money to the two companies to create infrastructure (and deploy Nissan LEAFs) in five separate American regions.¹⁵⁷

Coulomb Technologies. Coulomb is another charge point manufacturer start-up that has received a good deal of attention, largely by installing small numbers of chargers in relatively high profile locations. In early 2009, Coulomb publicly unveiled three charging stations in San Francisco in front of city hall.¹⁵⁸ In April of the same year, it installed a solar-powered charge station in Chicago as a piece of that city's International Olympic Committee bid.¹⁵⁹ Since then, it has showed off installations with corporate customers, including

Sierra Nevada Brewing Company, Rampart Casino & Resort, McDonald's, and Element Hotels, as well as continuing to work with municipalities such as Sonoma, CA; Nashville, TN; Hillsboro, OR; and Amsterdam, Netherlands.¹⁶⁰

Coulomb's strength lies in its networking capability. Its business model concentrates on selling hardware to businesses and municipalities while maintaining a central network that manages the consumer interface with the chargers. GEV owners can purchase a membership from Coulomb that provides them access to any of the company's chargers. Coulomb then administers customer validation, payment processing, and charge point location availability. Incidentally, Coulomb was also named as a partner in the development of ECotality's Department of Energy application and is expected to play a part in their infrastructure project.

Others. **Clipper Creek** has been a manufacturer of charging hardware for the Tesla Roadster, and provided the home charging points for the BMW Mini E project.^{161,162}

Shore Power has built on its truck-stop electrification business to produce GEV charge points and has installed a handful in Oregon.¹⁶³ **Aerovironment**, whose core business is in battery-powered unmanned aerial vehicles, was announced as Nissan's partner for establishing an infrastructure network in Washington, D.C.¹⁶⁴

EUROPEAN INFRASTRUCTURE PROVIDERS

Elektromotive. Elektromotive is the only charge point manufacturer with a large installed base that is being used commercially. The company has more than 150 Elektrobays distributed throughout the

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United Kingdom, concentrated largely in London.¹⁶⁵ The company is exporting charge stations throughout Europe and has received a large order from a research university in Saudi Arabia.¹⁶⁶ Although it is a small, private firm, Elektromotive has a fortuitous location in the backyard of London, one of the world’s leading EV cities.

ELECTRIC POWER SECTOR INTERFACE

To make any large deployments of infrastructure feasible in their interaction with the grid, the functioning of the hardware must be intelligently coordinated with grid operations. Few companies are focused solely on making this happen. Many smart grid developers—such as **GE**, **Cisco**, and **Silver Spring Networks**—may be capable, but none have chosen to focus on GEV infrastructure deployment. **GridPoint** is the lone exception. In 2008, GridPoint acquired **V2Green**, and in 2009 it announced partnerships with Coulomb and ECotality to develop the intermediate layer of software that will enable the smooth introduction of GEVs onto the grid.^{167, 168, 169}

Large installers of electrical transmission and distribution equipment are now beginning to recognize the opportunity that may come with EVs, both in terms of their existing business and new downstream opportunities. Both **Eaton** and **Siemens** have publicly announced development projects.^{170, 171} Although **GE** and **ABB** are pushing smart grid development, they have thus far been largely absent in the electric vehicle arena.

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Key to Terms

ACES 2009	American Clean Energy and Security Act of 2009.
Advanced Metering	Advanced electrical metering enables measuring and recording of usage data at regular short intervals and provides this data to both consumers and energy companies.
Advanced Transmission	Electricity distribution that employs digital metering to improve provider communication and monitoring capability as well as permit the efficient management of power flows, especially from variable renewable sources.
Ampere	A measure of electrical current which represents a flow of one coulomb of electricity per second.
ARRA 2009	American Recovery and Reinvestment Act of 2009.
Battery-Electric Vehicle (BEV)	A type of electric vehicle (see below) that is propelled by an electric motor and uses the chemical energy stored in on-board batteries to power the motor.
Blended Mode	In a hybrid-electric vehicle, operating in blended mode uses both an electric motor and a gasoline engine operating simultaneously and in conjunction to power the vehicle's drivetrain.
Carbon Dioxide Equivalent	The amount of carbon dioxide by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas.
Direct-Injection Transmission	A means of increasing power output and fuel efficiency in internal combustion engines. Gasoline is directly injected into the combustion cylinder, as opposed to fuel injection, when it is injected into the air intake.
Drivetrain	Also called the powertrain, the set of components for transmitting power to a vehicle's wheels, including the engine, clutch, torque converter, transmission, driveshafts or axle shafts, U-joints, CV-joints, differential and axles.
EISA 2007	Energy Independence and Security Act of 2007.
Electric Motor	Transforms electrical energy into mechanical energy. In a grid-enabled vehicle, the electricity is supplied by the battery.
Extended-Range Electric Vehicle (E-REV)	Sometimes called series or serial plug-in hybrids. E-REVs are electric drivetrain vehicles that rely on an electric motor to provide power to the drivetrain but which also include a gasoline internal combustion engine serving as an electrical generator to either provide electricity to the vehicle's electric motor (supplementing the battery's stored power) or to maintain the battery's state of charge as it nears depletion. The gasoline engine is not used to directly provide mechanical energy to the drivetrain.
Electric Vehicle (EV)	A vehicle propelled 100 percent by an electric motor, which forms part of an electric drivetrain. The power comes in the form of current from an on-board storage battery, fuel cell, capacitor, photovoltaic array, or generator.
Electric Vehicle Miles Traveled (EVMT)	The number of electric miles traveled nationally for a period of 1 year.
Electric Mile	For an electric vehicle, an electric mile is any mile in which the vehicle is propelled by an electric motor. For PHEVs or E-REVs, an electric mile is the total miles traveled multiplied by the percent of total power provided by electricity from the grid.
Electric Vehicle Supply Equipment (EVSE)	The hardware of electric vehicle charging infrastructure, including public charging stations and wall- or pole-mounted home vehicle chargers.
Fuel Cell	A device capable of generating an electrical current by converting the chemical energy of a fuel (e.g., hydrogen) directly into electrical energy. Fuel cells differ from conventional electrical cells in that the active materials such as fuel and oxygen are not contained within the cell but are supplied from outside.
Full Hybrid	Hybrids that provide enough power for limited levels of autonomous, battery-powered driving at slow speeds. Efficiency gains ranging from 25 to 40 percent.
Generator	Converts mechanical energy from an engine into electrical energy.
Grid-enabled Vehicle (GEV)	Electric or hybrid-electric vehicles that can be plugged directly into the electric grid to recharge onboard batteries.

Internal Combustion (IC) Engine	An engine that produces power by combining liquid fuel and air at high temperature and pressure in a combustion chamber, using the resulting gas expansion for mechanical energy. Conventional vehicle IC engines use two-stroke or four-stroke combustion cycles, which combust intermittently.
IOC	An oil company that is fully or majority owned by private investors.
Kilowatt (kW)	A unit of power equivalent to 1,000 watts, 1,000 joules per second or about 1.34 horsepower.
Kilowatt-hour (kWh)	A unit of energy or work defined as the amount of energy released if work is done at a constant rate of 1 kW for 1 hour, equivalent to 3.6 megajoules. Commonly used to bill for the delivery of electricity.
Light-duty vehicle (LDV)	An automobile or light truck, including passenger cars, minivans, cross-over vehicles, sport utility vehicles (SUVs) and trucks with gross vehicle weight less than 8,500 pounds.
Load	The amount of power (sometimes called demand) consumed by a utility system, individual customer, or electric device.
Mild Hybrid	Hybrid systems that only stop the engine during idle (while still running heat, A/C etc.), and instantly start it when the vehicle is required to move, providing efficiency gains in the 5 to 10 percent range.
NOC	An oil company that is fully or majority owned by a national government.
Original equipment manufacturer (OEM)	A company that produces a product designed for the end user, whether a consumer or another manufacturing firm. For example, an automotive OEM sells vehicles to consumers, typically through a dealer network; however a battery OEM may sell batteries only directly to automotive manufacturers.
Parallel Hybrid	Hybrids that have an IC engine and electric motor that both provide torque to the wheels. In some cases, the IC engine is the predominant drive system with the electric motor operating to add extra power as required. Others can run with just the electric motor driving.
Peak Demand (or Load)	The greatest electricity demand that occurs during a specified period of time.
Plug-In Hybrid Vehicle (PHEV)	A form of HEV that generally has larger batteries, allowing it to derive more of its propulsion from electrical power than from the IC engine. PHEVs are, as a result, far more efficient in their use of energy than typical HEVs. These batteries can be recharged by connecting a plug to an external electric power source.
Power Inverter	An electronic device that converts direct current (DC) into alternating current (AC) or AC into DC.
Powertrain	See drivetrain.
Residual Battery Value	The value of a battery established by the market after it has completed its primary purpose service life.
SAE J1772	The standard governing the design and characteristics of a conductive coupler for electric vehicle charging as recommended by the Society of Automotive Engineers (SAE). The protocol covers physical, electrical, communication, and performance requirements, and is designed to allow two conductors at varying voltage levels.
Series Hybrid	A vehicle which has an IC engine and electric motor, but only the electric motor provides torque to the wheels. A series hybrid is therefore essentially an electric vehicle with a fossil fuel recharging system on board. Both sources of power can be used if necessary.
Spare Oil Production Capacity	The amount of dormant oil production capacity which could theoretically be brought online within 30 days and which can be sustained for 90 days. Generally, only OPEC members maintain spare production capacity.
Total Cost of Ownership (TCO)	A measure of the entire undiscounted cost associated with the purchase, maintenance, usage, and disposal of a product spread evenly over the expected service life.
Transformer	A device that transfers electrical energy from one circuit to another, converting electricity from one voltage to another, performing the step-down or step-up necessary to enable high voltage, low current transmission, minimizing losses over long distances.
Transmission	Interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric systems.
Vehicle Miles Traveled (VMT)	The number of miles traveled nationally by vehicles for a period of 1 year.

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Partners & Consultants



Securing America's Future Energy (SAFE) is a nonpartisan, not-for-profit organization committed to reducing America's dependence on oil and improving U.S. energy security in order to bolster national security and strengthen the economy. SAFE has an action-oriented strategy addressing politics and advocacy, business and technology, and media and public education.



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The Electrification Roadmap is a comprehensive report that outlines a vision for a fully integrated electric drive network in the United States. The report examines the challenges facing electrification, including battery technology and cost, infrastructure financing, regulatory requirements, electric power sector interface, and consumer acceptance issues. The Roadmap provides policymakers and business leaders with a framework for overcoming these challenges in order to drive meaningful reductions in U.S. oil dependence.

Electrification Coalition 1111 19th Street, NW Suite 406 Washington, DC 20036 **TEL** 202-461-2360 **FAX** 202-461-2379 **ElectrificationCoalition.org**

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