Electrification Roadmap

REVOLUTIONIZING TRANSPORTATION AND ACHIEVING ENERGY SECURITY

Electrification Coalition

PART ONE

The Case for Electrification

A soldier keeps watch from a checkpoint in Iraq.

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]

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.

1 BP Statistical Review 2009, at 12.
2 Id. at 40.
3 AER 2008, at 77 (Table 5.5).
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 United States.

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.

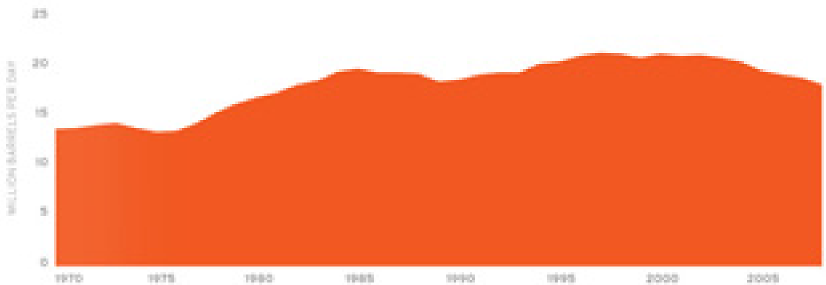
More recently, however, high and volatile oil prices have been the result of factors that should be considered structural as opposed to transitory. Economic growth in developing countries like China and India has added a new component to the world oil demand picture. In total, world demand for oil increased 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

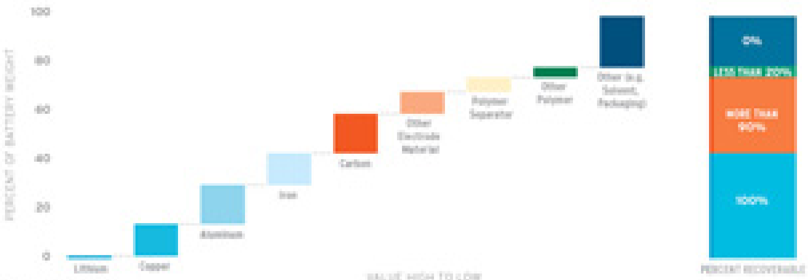
7 BP Statistical Review 2009, at 11.
8 Id.

FIGURE 1A OECD OIL PRODUCTION



Source: BP, plc

FIGURE 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.

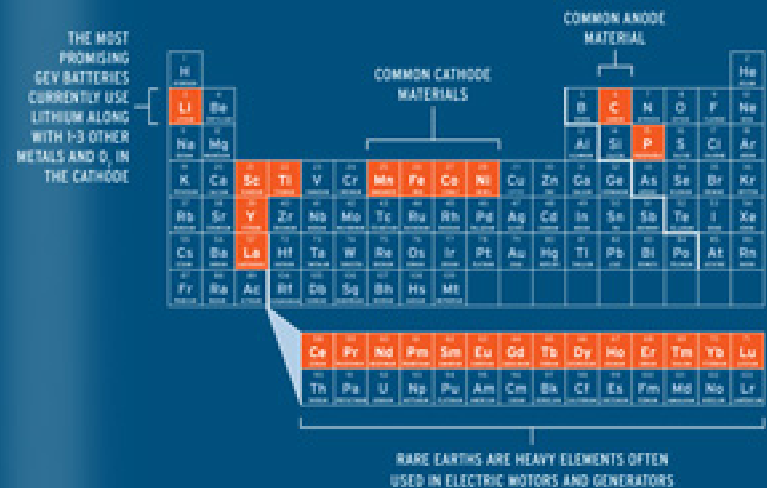
OTHER METALS

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.



PART TWO

Challenges & Opportunities

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.

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 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.

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

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

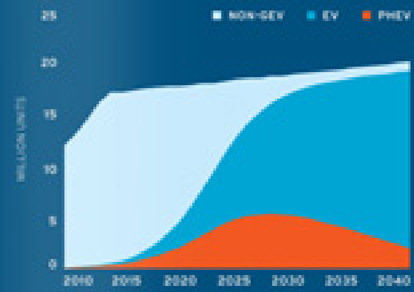


FIGURE EG REQUIRED FLEET PENETRATION

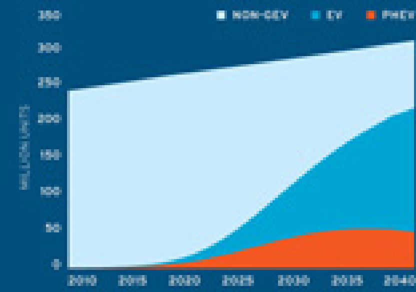


FIGURE EH VEHICLE MILES TRAVELED

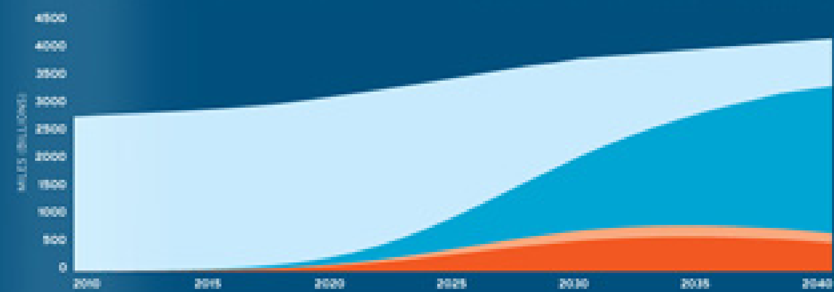
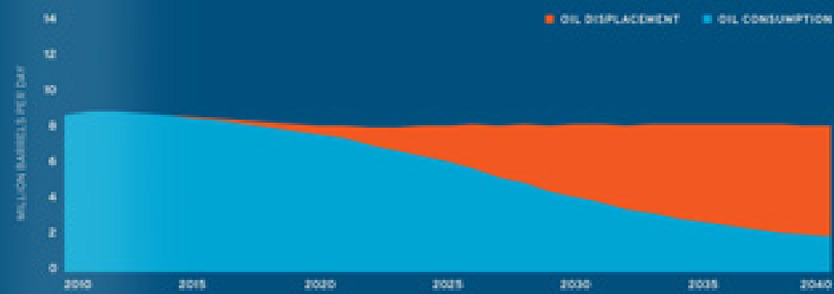


FIGURE EI EXPECTED LIGHT-DUTY VEHICLE OIL ABATEMENT

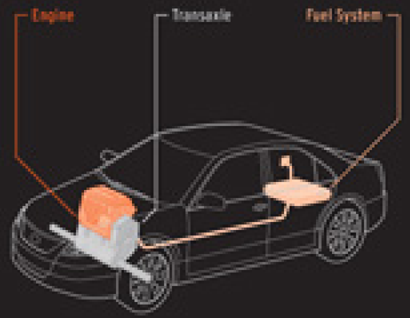


Source: PRTM Analysis

FIGURE 2B

Vehicle Configurations

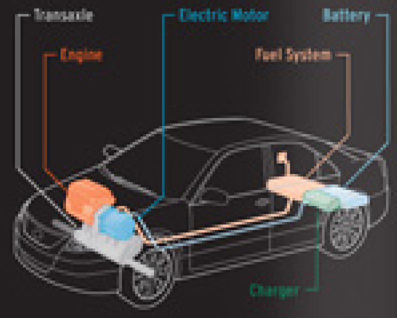
INTERNAL COMBUSTION ENGINE VEHICLE



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)

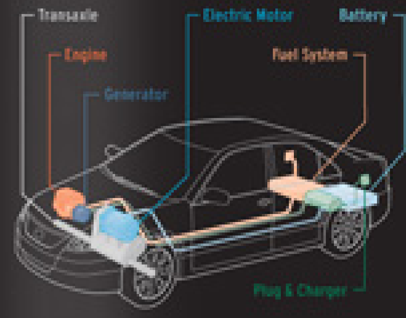


KEY FEATURES

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.

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.

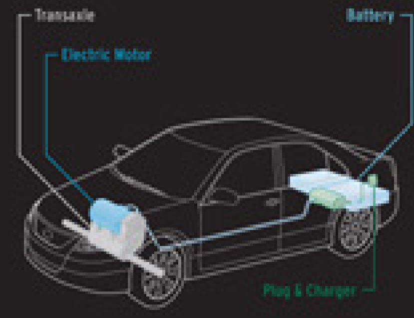
PLUG-IN HYBRID ELECTRIC VEHICLE (PHEV)



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

FIGURE 1P

Electrification Architecture

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.

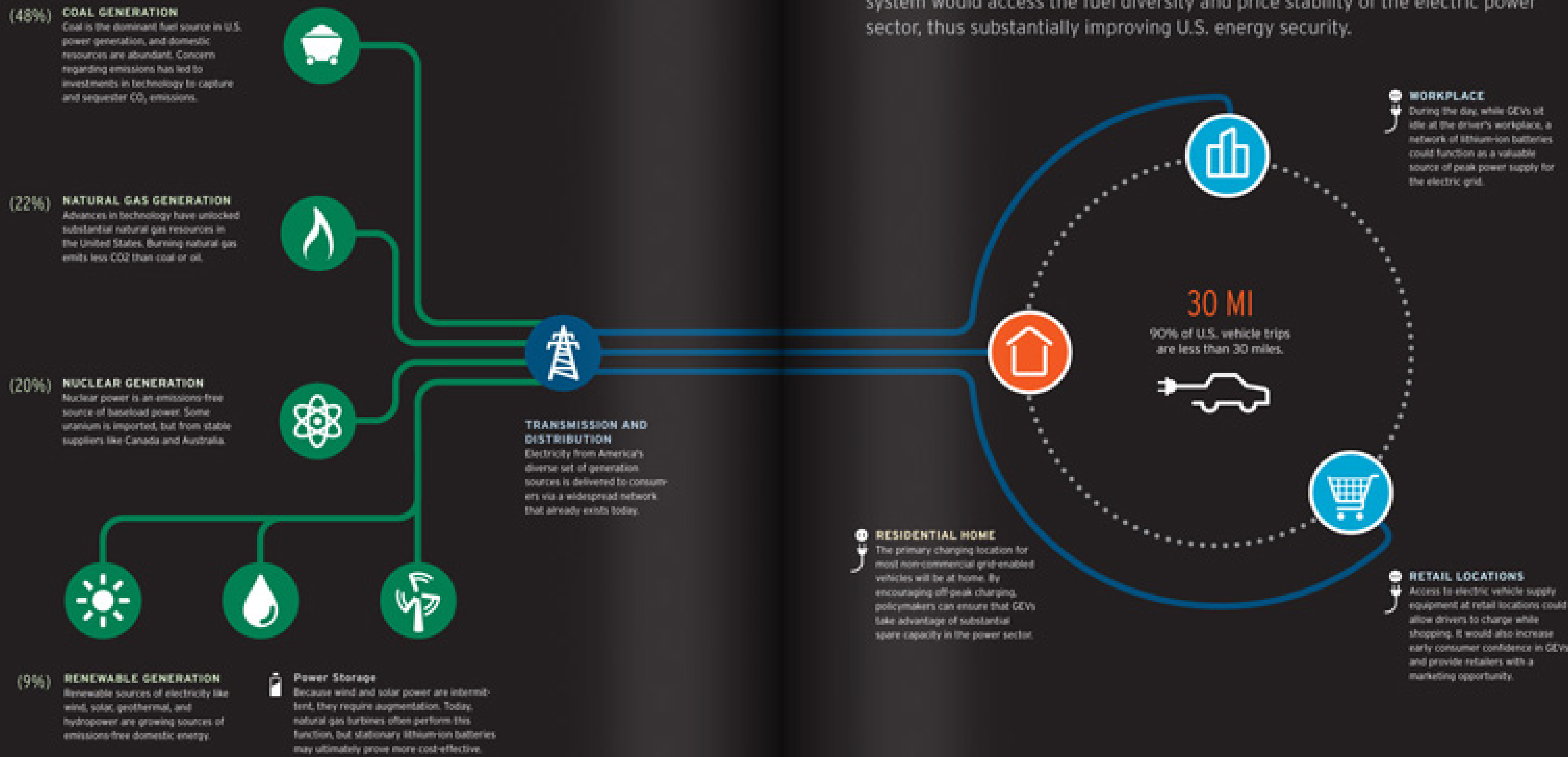
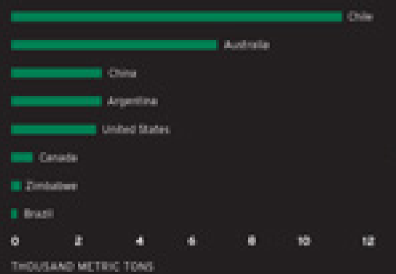


FIGURE 2G

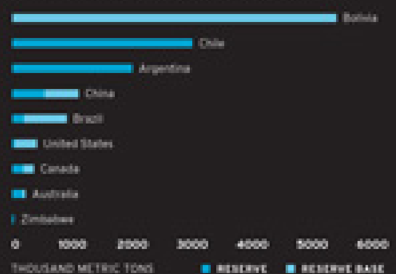
Lithium: Global State of Play

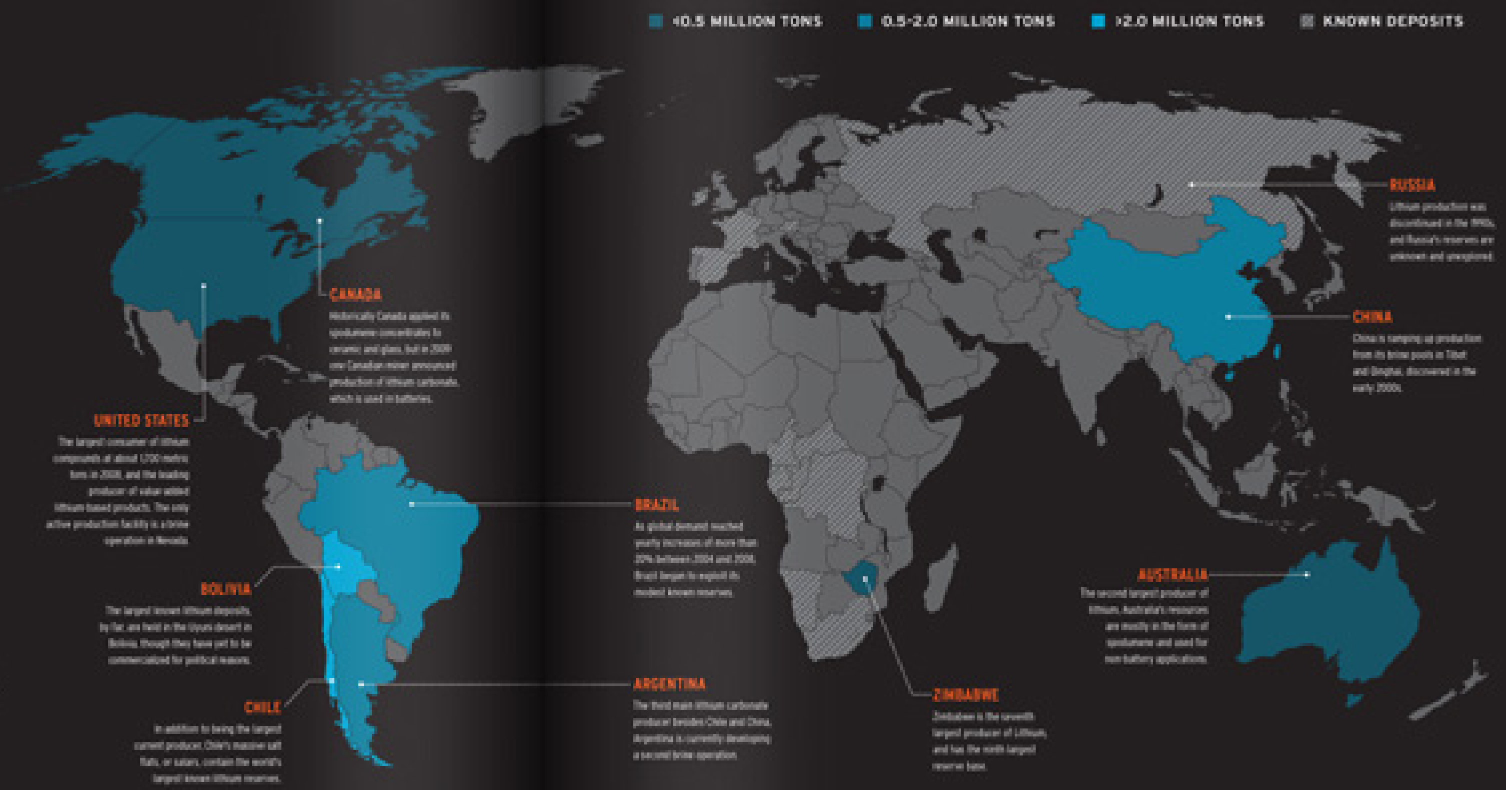
Total identified world lithium resources stand at around 13.4 million tons, according to USGS. Reserve estimates must be understood in the context of demand, which has thus far required only the cheapest and most accessible lithium to be developed. Further, unlike oil, lithium is recyclable. Though not 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

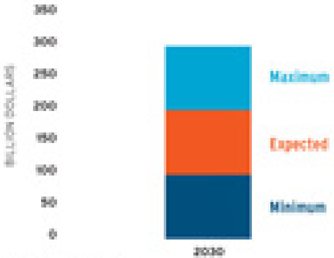
THE NETWORK OPERATOR MODEL

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.

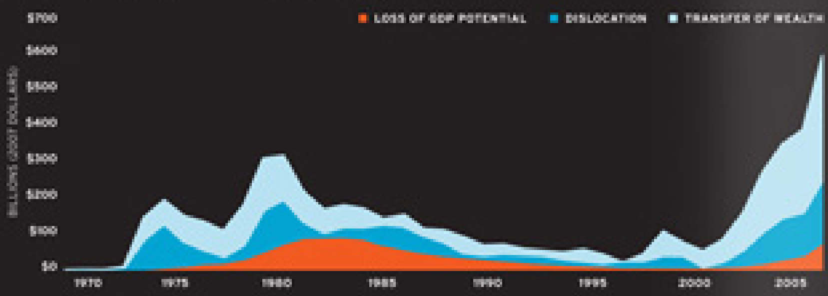
The bright lights of Detroit and dimmer lights of Windsor, Ontario.

PART THREE

Analysis of the Goal

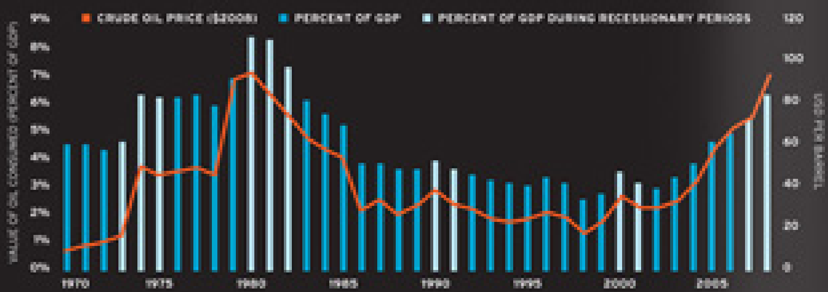
The High Five Freeway Interchange, Dallas, TX. Before grid-enabled vehicles fill America's highways, they will need to present consumers with a compelling value proposition.

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 www1.eere.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.

PART FOUR

Strategic Deployment

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.

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 CO_2.

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.

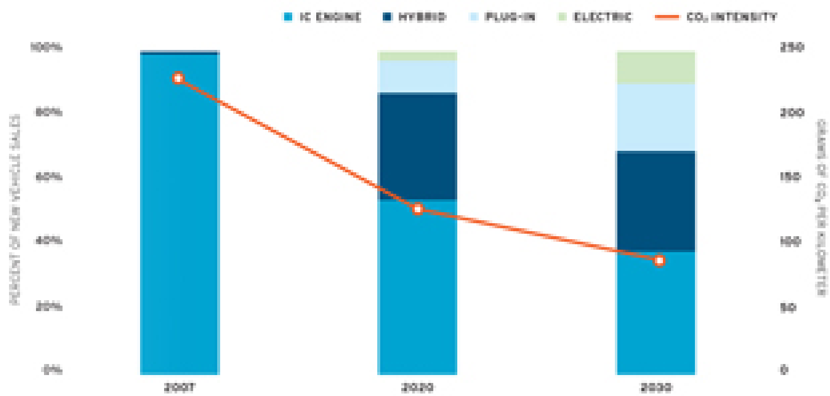
It is important to recognize that curbing emissions is a global issue and that there is not yet an international consensus on a long-term stabilization objective or on the required changes in emissions trajectory to meet such a goal. Nonetheless, international discussions are increasingly centered on a stabilization level that ranges between 450 and 550 parts per million (ppm) CO_2 equivalent (CO_2-eq).[48] According to the United Nations Intergovernmental Panel on Climate Change, stabilization at 450 ppm CO_2-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, CO_2—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 40.5 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 CO_2-eq stabilization target would require average annual per-capita CO_2-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.

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.

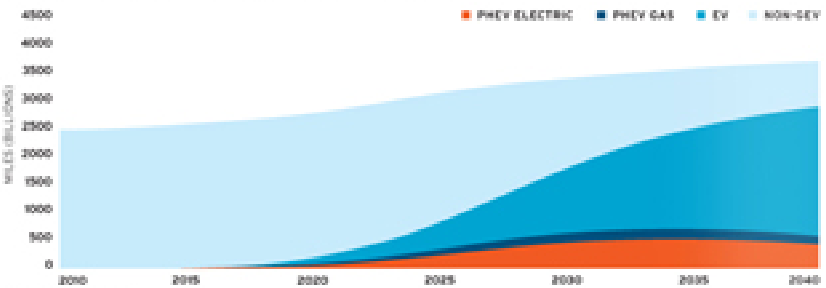
3.1.2 A NOTE ON TECHNOLOGY

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.

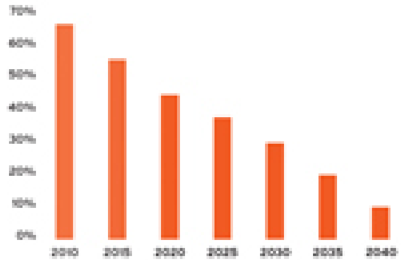
However, the dual system approach is also cost intensive. In essence, expensive components from two different drivetrains are used to manufacture a single hybrid gasoline-electric vehicle. As long as battery prices are high, the hybrid gasoline-electric powertrain system is cost-effective, because EVs 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.

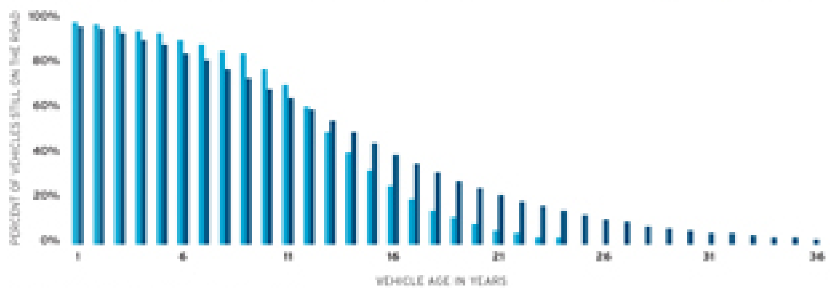
3.1.3 ELECTRIC VEHICLE ADOPTION RATES

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