MEMORANDUM FOR THE PRESIDENT

FROM: SECRETARY OF TRANSPORTATION

SUBJECT: Plug-In Hybrids

To reduce oil dependence, nothing would do more good more quickly than making cars that could connect to the electric grid.

The United States has a vast infrastructure for generating electric power. However, that infrastructure is essentially useless in cutting oil dependence, because modern cars can't connect to it. If we built cars that ran on electricity and plugged into the grid, the potential for displacing oil would be enormous.

Plug-in hybrid electric vehicles (PHEVs) are a game-changing technology. They can break our oil addiction, cut driving costs and reduce pollution. To help end U.S. oil dependence, there is no higher priority than putting millions of plug-in hybrids on the road soon.

A QUICK HISTORY OF ELECTRIC CARS

The first cars ran on electricity. In 1900, electric cars outsold all other kinds. However, early electric cars could travel no more than a few miles on a single charge. Cars with internal combustion engines, fueled by petroleum, could go much farther. During the early decades of the 20th century, petroleum-fueled cars took over the market.

For almost 90 years, electric vehicles were limited to niche applications. Golf carts and fork lifts used electric motors, but on-the-road vehicles almost never did. Then, in the early 1990s, the U.S. Congress and State of California passed clean air rules designed to spur innovation by major automakers. Several responded with new models of electric cars.

Unfortunately the electric cars of the 1990s produced more controversy than clean air. General Motors EV-1 was the most controversial. Leased mainly in California, with a range of 80-140 miles, the EV-1 won hundreds of wildly enthusiastic owners. But GM considered overall buyer interest inadequate and discontinued production. Major auto manufacturers lobbied successfully to change the California rules requiring them to build "zero emission" cars.

In the late 1990s, Toyota and Honda began marketing the first "hybrid electrics." A hybrid electric vehicle combines an internal combustion engine and electric motor. The engine runs on oil and the electric motor draws power from a battery. The battery is recharged with extra power from the engine (for example, when the car is going downhill) and energy captured from the brakes (in a process known as "regenerative braking"). When the battery is depleted, the vehicle runs on its gas tank. This solves the problem of short driving range that plagued other electric vehicles, while providing better fuel efficiency, torque and other measures of engine performance than a car with an internal combustion engine only.

Beginning in 2003, buyer interest in hybrid electric vehicles began to explode. By 2004, buyers were forced to wait months as dealers struggled to keep up with growing demand. Worldwide, more than 1,000,000 hybrid electric vehicles have now been sold.

2. THE NEXT STEP—PLUG-IN HYBRIDS

The next big step in automotive technology is the plug-in hybrid electric vehicle (PHEV). Like conventional hybrids, PHEVs combine an electric motor and internal combustion engine. But, as the name suggests, there is an important additional feature. Plug-in hybrids can be recharged from the electric grid. They can—quite literally—be plugged into a wall socket.

The idea is simple, but the consequences are far-reaching:

- With plug-in hybrids, many drivers would need no petroleum for their daily commute. Cars could be recharged at night and many drivers could travel back and forth to work or around town using the car's electric motor only.
- Driving costs would drop dramatically. At national average electricity prices, PHEVs would cost the equivalent of roughly 75 cents per gallon to drive when operating on their electric motors. (When charging, a plug-in hybrid car draws roughly the same amount of electricity as a home space heater.)

- As with many electric cars, torque and acceleration would be excellent.

Said one enthusiast who converted his Toyota Prius to a plug-in: "Everyone wants to drive electric cars, they just don't know it yet."

The biggest barrier to mass production is battery technology. Adding a plug-in feature to a conventional hybrid engine requires adjustments that increase the cost and size of the batteries, while shortening their expected life. Extra costs now run roughly from $8,000 to $11,000 per car. These costs are expected to drop sharply, however, with mass production and advances in battery technology. Many innovators—supported by substantial venture capital—are at work on new high-performance batteries.

In late 2006, General Motors announced plans to produce a plug-in hybrid, known as the Chevy Volt, and displayed a prototype at the Detroit Auto Show. Toyota and other manufacturers have also indicated they are looking seriously at PHEVs. The time frame for bringing these cars to market is unclear.

Plug-in hybrids are coming. Private investments and the predictable pace of innovation will help bring them to market, slowly, during the next decade. Federal policies could dramatically accelerate this pace. The balance of this memo summarizes the benefits of PHEVs and suggests polices to put millions on the road soon.

3. IMPACT ON OIL DEPENDENCE

Plug-in hybrids would cut oil use significantly. They would dramatically reduce U.S. vulnerability to disruptions in oil supplies.

With plug-in hybrids, many drivers would use little or no petroleum each day. National surveys have found that 60% of Americans travel 30 miles or less each day. One recent study, using global positioning system (GPS) technology to track vehicles in St. Louis, found that 50% of vehicles monitored drove 30 miles or less each day. With PHEVs, most or all of these miles could be driven using electricity instead of oil.

The oil savings would be substantial. With driving patterns observed in the St. Louis survey, a PHEV able to go 20 miles on an electric charge (a "PHEV20") would get approximately 70 miles per gallon on average. A PHEV able to go 40 miles on a charge (a "PHEV40") would get approximately 134 miles per gallon. This is much better performance than a typical car (21 mpg average) or conventional hybrids.

One study found that, if all cars were PHEV20s, gasoline consumption would fall roughly 40%. Another study, using different survey data, put the figure at 50%. A third put the figure at 56%. For PHEV40s, studies project gasoline savings of more than 60%.

Yet the contribution of plug-ins to ending oil dependence is much greater than the gallons saved. PHEVs would also allow our vehicle fleet to access an important reserve fuel source, dramatically reducing U.S. vulnerability to disruptions in oil supply.

Most utilities have substantial unused electric generating capacity at night, when loads are low. In addition, all electric utilities maintain reserve generating capacity—known as "peaking power"—for days of unusually high demand. (Typically, utilities use this peaking power only a few hundred hours per year.) This excess and reserve capacity could provide an important backup fuel source for our vehicles, if cars could connect to the electric grid.

Consider the impact of a significant oil supply disruption on two drivers: one with a conventional car and the other with a plug-in hybrid. Both drivers would face wildly inflated oil prices and, in the most extreme case, problems obtaining gasoline. The owner of the conventional car would be required to pay inflated gasoline prices or stop driving. The owner of the plug-in hybrid could shift more driving to the car's electric motor. This might cause some inconvenience, such as more frequent recharging or shorter trips. But driving costs would climb modestly, if at all. Even in the event of a catastrophic disruption in oil supplies, the second driver would be mobile.

The presence of large numbers of PHEVs in the vehicle fleet would transform the relationship between the United States and leading oil exporters. We would retain an interest in reliable oil supply and stable prices, but our crushing dependence would be dramatically diminished.

This U.S. reserve capacity for generating electricity is an important asset, maintained at considerable cost. We should use it to help end our oil dependence. With plug-in vehicles, we can do just that.

4. ENVIRONMENTAL IMPACTS

Plug-in hybrids have two important environmental benefits. First, they dramatically improve urban air quality. Second, they significantly reduce emissions of heat-trapping gases.

PHEVs may have some small adverse environmental consequences as well. In some regions, plug-ins may cause more particulate emissions, mostly away from population centers. Disposal of used batteries may require additional landfill space, although most will likely be recycled.

a. *Urban Air Quality*

Plug-in hybrids emit nothing from their tailpipes when driving in all-electric mode. As a result, plug-ins would dramatically improve air quality in many cities. The exact amount of improvement would depend on driving patterns, vehicle design, and other factors, but would almost certainly be substantial. One study predicts a 98% reduction in emissions of carbon monoxide, a leading smog precursor, for each PHEV.

The benefits could be enormous. Vehicles are the largest source of air pollution in the United States, producing more than three fourths of the carbon monoxide and a half of the nitrogen oxides in the nation. Better air quality would mean fewer children with asthma, greater worker productivity, and improved quality of life. In some cities, air quality could reach levels not experienced for more than 50 years.

b. *Global Warming*

Petroleum is a leading source of heat-trapping gases. By cutting oil use, plug-in hybrids can play an important role in fighting global warming.

Of course, the power to recharge a plug-in hybrid must come from somewhere. In much of the United States, that somewhere will be a coal-fired power plant. Yet coal produces more heat-trapping gases per unit of energy than oil. Does that mean that plug-in hybrids could make the global warming problem worse?

The simple answer: no. Plug-in hybrids reduce emissions of heat-trapping gases, even if the power to recharge batteries comes from a coal-fired power plant. The reason: A traditional internal combustion engine is astonishingly inefficient. With hundreds of moving parts constantly creating friction, an internal combustion engine wastes much of its energy in the form of excess heat. (That's the main reason for your car's cooling system.) The "thermal efficiency" of an internal combustion engine—its ability to convert fuel to useful work—is roughly 20%. The thermal efficiency of even an old-fashioned pulverized coal plant is roughly 33% to 34%. Newer coal units have efficiencies of more than 40%.

Consider this calculation:

1. Burning a gallon of gasoline releases roughly 20 pounds of carbon dioxide into the atmosphere.
2. A gallon of gasoline moves the average U.S. vehicle roughly 21 miles.
3. That means *the average car releases just under 1 pound of carbon dioxide for each mile traveled.*
4. Generating a kilowatt-hour of energy at the average U.S. coal plant releases roughly 2.1 pounds of carbon dioxide into the atmosphere.
5. A kilowatt-hour moves a first generation PHEV roughly 3 miles.
6. That means a *first-generation PHEV recharged with energy from a coal-fired power plant will release roughly 0.7 pounds of carbon dioxide per mile* when driving on its electric motor.

In other words, from a global warming standpoint, driving a PHEV charged with energy from a coal plant is *better* than driving an average vehicle filled with oil. Driving a PHEV charged with energy from a standard wall socket—which draws only part of its power from coal—is *much better* from a global warming standpoint

Roughly half of the electricity in the United States comes from coal. Other electric power sources emit far fewer heat-trapping gases than coal plants emit. Recent studies have found that, with today's grid and driving patterns, plug-in hybrids would reduce total emissions of heat-trapping gases from vehicles in the United States by 27% to 37%.

Furthermore, it's possible to drive a plug-in hybrid without producing any heat-trapping gases at all. If a plug-in is recharged from a wind turbine or solar panel, for example, the miles driven on that charge have essentially no impact on global warming. In some regions of the country, wind resources are especially good at night, when many drivers will be recharging cars. PHEVs are an especially good way to capture wind energy.

The global warming benefits of plug-in hybrids will depend on many factors, including sources of electric power (coal, nuclear, natural gas, hydro, wind or solar) and driving patterns (miles driven on electricity versus miles driven on gasoline). With today's electric grid, the benefits are substantial. As the grid gets cleaner in the decades ahead, those benefits would grow.

c. <u>*Particulates*</u>

Increased coal generation due to PHEVs would lead to increases in other types of pollution. Many but not all of these increases would be offset by declining oil combustion or controlled through additional investment in pollution control devices at coal plants. However, emissions of particulates (better known as soot) would likely increase in some regions of the country with widespread use of PHEVs. The additional particulates would mostly be emitted away from urban population centers.

d. *Battery Disposal*

Large-scale deployment of plug-in vehicles could add millions of additional batteries to the solid waste stream. However, this could be managed with minimal environmental problems at reasonable cost.

First, the batteries most likely to be used in plug-in hybrids are environmentally benign. Lithium ion batteries, for example, are nonhazardous and considered safe for disposal in municipal waste systems. Nickel metal hydride batteries, used in the Toyota Prius and other conventional hybrids, are nonhazardous as well. Batteries with highly toxic elements such as lead, cadmium and mercury are very unlikely to be used to power plug-in hybrids.

Second, battery recycling programs are well-established and will likely be extended to batteries from plug-in hybrids. Today roughly 80% to 95% of car batteries are recycled. The Rechargeable Battery Recycling Corporation runs a nationwide program dedicated to recycling used rechargeable batteries. Modifying and scaling up the programs already in place to handle the additional batteries from plug-in hybrids should not present significant problems. Indeed, many used PHEV batteries could be used by utilities or others for stationary energy storage.

Finally, the first plug-in hybrid batteries will not be ready for disposal for almost a decade. This will provide ample time to shape and implement programs for safe battery disposal.

5. IMPACT ON ELECTRIC POWER SYSTEMS

U.S. power plants are more than adequate to handle increased electricity demand from plug-in vehicles. Even with plug-ins making up half the vehicle fleet—several decades away under the most aggressive scenarios—electricity demand would increase only 4% to 7% from current levels. Much of this additional demand would be at night, when electricity loads are low and huge amounts of generating capacity sits unused. One recent study suggest that more than 200 million plug-ins could be driven daily in the United States without the need for new electric generating capacity.

Plug-ins vehicles would provide utilities with a range of benefits. First, plug-ins would provide utilities with additional revenue. Second, plug-ins would reduce variations in electric load between night and day. (Such "load leveling" improves utilities' operating efficiency and reduces unit costs.) Third, plug-ins could even become a *source* of power, helping utilities meet peak loads.

This final benefit—sometimes called "vehicle-to-grid," or V2G—could be especially compelling. Drivers could recharge car batteries at night and then sell electricity not used for driving back to the grid during the day. This would help many regions meet electric needs during summer months, when air-conditioning creates extraordinary daytime electricity demand. As "time-of-day metering" becomes more common, individuals could use this technique to help cut electric bills. Plug-in vehicles could also provide backup power to households during outages caused by downed wires or storms.

Finally, plug-ins vehicles are an especially good way to use wind power. In most areas wind is greater at night, when electricity demand is low. With plug-ins, wind power could be used to recharge car batteries at night, essentially replacing the oil currently used to move vehicles with wind.

6. BARRIERS

Why aren't plug-in hybrids on the road today? Mainly, because the batteries required are expensive and might not last for the life of a car.

A plug-in hybrid needs a high-performance battery. PHEV batteries must deliver sufficient power for acceleration and high speeds. They must store enough energy for the car to travel many miles. They must withstand several thousand "deep discharge cycles." (The more often a battery is depleted, the shorter its life.) Performance requirements are especially great if the vehicle is designed to run entirely on its electric motor for a certain distance after each charge.

At the same time, batteries must be small enough to fit within the car's frame, light enough to transport, and cheap enough to be competitive.

Not surprisingly, these battery design problems present a challenge. Lead-acid batteries, used for most car electrical systems, are far too heavy. Nickel-metal hydride batteries, used with great success in conventional hybrids, are too heavy for many plug-ins as well.

Much attention has focused on lithium ion batteries, the kind widely used in computer laptops. Lithium is the lightest metal (and third lightest element). Lithium ion batteries can deliver more power and energy per pound than any other battery on the market today. More than $1 billion is being spent on research and development of these batteries each year.

However, lithium ion batteries are expensive. They generate lots of heat and have been known to catch fire, leading to widely publicized recalls of laptop batteries. Fortunately the fire risk, or "thermal run-away" problem, is easily solved by adding certain compounds to a lithium ion battery. Standards requiring the addition of these compounds to any lithium ion car batteries would be in the public interest.

In designing batteries for plug-in hybrids, engineers consider many questions. Among the most important are:

- How much power can the battery deliver?
- How much energy can it store?
- How much does it weigh?
- How big is it?
- How quickly can it recharge?
- How many times can it be recharged?
- Does it lose charge with time?
- Can it operate in hot and cold temperatures?
- Does it present fire risks?
- How much does it cost?

At present, batteries that meet performance specifications for plug-in hybrids can be manufactured at a price premium of approximately $8,000 to $11,000 per vehicle. These costs would decline with mass production. In addition, energy capacity of batteries is improving at 5% to 8% per year, according to some estimates.

At the same time, revolutionary advances in battery technologies may be near.

Nanotechnology may revolutionize batteries in the next few years. Nano processes can be used to make electrodes with much larger surface areas, for example, dramatically improving battery performance. At least one nanotech company claims its product can store 3 to 4 times the energy and last 20 times longer than an existing battery, while recharging in less than 2 minutes. Several companies are working to bring nanotech batteries to market.

I believe that advances in battery technology will follow quickly from large orders for plug-in hybrids. Batteries that meet the needs of PHEV drivers are close. With leadership from the federal government, we can bring them to market soon.

7. POLICY RECOMMENDATIONS

During the next decade, plug-in hybrid vehicles will begin to enter the marketplace. However, the pace of commercialization will be slow. To dramatically speed the pace at which PHEVs enter the market, I recommend the five steps: federal purchases, consumer tax credits, a grand bargain with Detroit, a federal battery guarantee program and advanced battery research.

a. *Federal Purchases*

Each year, the federal government buys more than 65,000 new cars. These purchases should be used to transform the automobile industry.

I recommend that the federal government issue an open order for 30,000 plug-in hybrid vehicles, offering to pay an $8,000 premium for each one. The General Services Administration, which administers federal vehicle purchases, should commit to repeat this order every year after the first vehicles are delivered, with the premiums declining over time. All vehicles would need to meet basic performance requirements. I recommend stating a formal policy that 50% of noncombat vehicles purchased by the federal government be PHEVs, once they become commercially available.

These steps would quickly jump start the market for PHEVs by generating substantial new investment in battery technology, helping finance conversion of existing production lines, and creating economies of scale. Total cost for the program would be $1.2 billion, spread out over roughly a decade.

State, utility, and private sector fleets are already making such commitments. Plug-In Partners, a campaign by several hundred state and local governments, utilities and nonprofits, has already generated more than 11,000 "soft orders" for PHEVs.

b. *Consumer Tax Credits*

I recommend $8,000 tax credits for purchasers of the first million PHEVs. This would bring PHEV costs roughly in line with those of other cars. A smaller tax credit, say $4,000, could be offered for purchasers of the second million. This bold stroke would dramatically accelerate commercialization of PHEVs.

Credits should be fully refundable, so Americans with little or no tax liability could benefit. Credits should reduce liability under the Alternative Minimum Tax, so the tens of millions of Americans affected by the AMT can benefit as well. Cars should meet strong fuel efficiency standards when driving on their internal combustion engines to be eligible.

The total of the cost of this program would be $12 billion, spread out over several years.

c. *Grand Bargain with Detroit*

The financial position of major U.S. automakers has never been worse, with some analysts speculating about impending bankruptcies. One reason is the cost of retiree health care. For the legacy automakers (GM, Ford and Chrysler), these costs average $680 per vehicle, hurting competitiveness and straining corporate balance sheets. For financially weak companies, converting manufacturing facilities to produce plug-in hybrids or other fuel-efficient cars may be especially difficult.

I recommend you propose a federal trust fund to help automakers invest in plug-in hybrids and other fuel-saving technologies. Several structures are possible. The fund could reimburse qualifying expenses involved in retooling production lines, or it could make payments based upon the fuel efficiency of new vehicles sold. Costs could be capped at any level, with funds allocated based upon superior performance in terms of oil savings or related factors.

d. *Federal Battery Guarantee Corporation*

Car makers identify battery life as a major barrier to mass production of PHEVs. Customers expect extended warranties on all major auto components, yet current batteries cannot reliably perform for extended periods. Providing extended battery warranties (such as for 10 years/100,000 miles) could be expensive.

There is a strong national interest in overcoming this barrier. One solution is a Federal Battery Guarantee Corporation, to help jump start the market for PHEVs by spreading the risk of battery obsolescence. The FBGC would reimburse car makers 100% of any costs incurred under extended battery warranties for the first 20,000 PHEVs sold. It would cover 80% of costs under extended battery warranties for the second 20,000 sold; 60% of costs for the third 20,000; 40% of costs for the fourth 20,000; and 20% of costs for the fifth 20,000. It could adjust this schedule, within limits, to help achieve the objective of bringing PHEVs to market.

Such a program would have three benefits. First, it would directly address a core concern of auto manufacturers reluctant to bring PHEVs to market. Second, it would reward early movers, giving the greatest benefits to those who bring PHEVs to market first. Third, it would stimulate improvements in battery technology, making the program itself less important over time.

Costs of the program are difficult to estimate, since the likelihood of battery obsolescence during the extended warranty period is speculative. With the schedule suggested above and average battery replacement costs of $8,000, the theoretical maximum would be roughly $500 million over 10 years, with most costs incurred toward the end of this period. Actual costs could be much lower.

e. *Advanced Battery Research*

The federal government should increase spending on battery research. Such research can make an important contribution to the performance of plug-in hybrids over time. Private sector research and development will remain focused on technologies with prospects for near- or medium-term commercial payoff. Federal research should focus on technologies where payoff will be over the long term.

The U.S. Advanced Battery Consortium, a partnership of the major U.S auto and the U.S. government, dates to 1991. The consortium has played a role in some battery advances in the past decade, but needs a more focused mission and additional funding.

Over the years, federal energy research has helped produce important breakthroughs, such as electronic ballast for fluorescent lamps, low-e glass for windows and advanced turbine systems.[47] Growing federal support for battery research can help to accomplish the breakthroughs that will transform our children's lives.

8. CONCLUSION

Plug-in hybrid electric vehicles are a game-changing technology. They can break our oil addiction, cut driving costs and reduce pollution.

Some might object to the proposals above on the grounds that government should stay out of the marketplace. In fact, the federal government has been a central player in transportation and energy markets for many years. Federal funds built the interstate highway system and continue to provide much more support for road building than mass transit. Governments at all levels are central players in electricity markets. For more than a century, governments have been using eminent domain authority to help build a pipeline network for moving oil at low cost. Perhaps most centrally, the U.S. military helps protect oil flows around the world, transforming markets for that product.

Plug-in hybrids would help address important national security, environmental and economic problems. Bringing them to market quickly should be a top national priority.