THE PLUG-IN HYBRID ELECTRIC VEHICLE ACT OF 2006 (DISCUSSION DRAFT)

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE

HOUSE OF REPRESENTATIVES

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THE PLUG–IN HYBRID ELECTRIC VEHICLE ACT OF 2006 (DISCUSSION DRAFT)

WEDNESDAY, MAY 17, 2006

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON ENERGY,
COMMITTEE ON SCIENCE,
Washington, DC.

The Subcommittee met, pursuant to call, at 10:09 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Judy L. Biggert [Chairwoman of the Subcommittee] presiding.

COMMITTEE ON SCIENCE
SUBCOMMITTEE ON ENERGY
U.S. HOUSE OF REPRESENTATIVES

The Plug-in Hybrid Electric Vehicle Act of 2006

Wednesday, May 17, 2006

10:00 AM – 12:00 PM
2318 Rayburn House Office Building

Witness List

Dr. Andrew Frank
Professor
Mechanical and Aeronautical Engineering Department at The University of California, Davis

Mr. Roger Duncan
Deputy General Manager
Austin Energy in Texas

Dr. Mark Duvall
Technology Development Manager
Electric Transportation & Specialty Vehicles in the Electric Power Research Institute's (EPRI)
Science & Technology Division

Mr. John German
Manager
Environmental and Energy Analyses for American Honda Motor Company

Dr. Cliff Ricketts
Professor
Agricultural Education in the School of Agribusiness and Agriscience at Middle Tennessee State University

Dr. Danilo Santini
Senior Economist
Energy Systems Division of Argonne National Laboratory's Center for Transportation Research

HEARING CHARTER

SUBCOMMITTEE ON ENERGY
COMMITTEE ON SCIENCE
U.S. HOUSE OF REPRESENTATIVES

The Plug-In Hybrid Electric Vehicle Act of 2006 (Discussion Draft)

WEDNESDAY, MAY 17, 2006
10:00 A.M.–12:00 P.M.
2318 RAYBURN HOUSE OFFICE BUILDING

1. Purpose

On Wednesday, May 17, 2006, the Energy Subcommittee of the House Committee on Science will hold a hearing on a discussion draft of legislation to promote research and development (R&D) on plug-in hybrid electric vehicles and related advanced-vehicle technologies.

2. Witnesses

Mr. Roger Duncan is the Deputy General Manager of Austin Energy in Texas and serves on the board of the Electric Drive Transportation Association.

Dr. Mark Duvall is a Technology Development Manager for Electric Transportation & Specialty Vehicles in the Electric Power Research Institute's (EPRI) Science & Technology Division. He currently oversees EPRI's Grid-Connected Hybrid Electric Vehicle Working Group and is EPRI's technical lead for the DaimlerChrysler-EPRI Plug-in Hybrid Electric Sprinter Van Program. EPRI is the research arm of the U.S. electric utility industry.

Dr. Andrew Frank is a Professor in the Mechanical and Aeronautical Engineering Department at the University of California, Davis, and the Director of the UC Davis Hybrid Electric Vehicle Research Center.

Mr. John German is Manager of Environmental and Energy Analyses for American Honda Motor Company. Mr. German is the author of a variety of technical papers and a book on hybrid gasoline-electric vehicles published by the Society of Automotive Engineers.

Dr. Cliff Ricketts is a Professor of Agricultural Education in the School of Agribusiness and Agriscience at Middle Tennessee State University. Dr. Ricketts has designed and built engines powered from a variety of sources including ethanol, methane, soybean oil, and hydrogen.

Dr. Danilo Santini is a Senior Economist in the Energy Systems Division of Argonne National Laboratory's Center for Transportation Research, as well as a former Chair of the Alternative Fuels Committee of the National Academy of Sciences' Transportation Research Board.

3. Overarching Questions

The hearing will address the following overarching questions:

1. What major research, development, and demonstration work remains on plug-in hybrid electric vehicle technologies? How should this work be prioritized?
2. What are the largest obstacles facing the widespread commercial application of plug-in hybrid electric vehicles and what steps need to be taken to address these hurdles? (batteries, infrastructure, consumer preference, automotive inertia, cost-competitiveness, etc.)
3. How does the Federal Government support the development of plug-in hybrid electric vehicle technologies? What can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles?

4. Does the discussion draft of the *Plug-In Hybrid Vehicle Act of 2006* address the most significant technical barriers to the widespread adoption of plug-in hybrid electric vehicles?

4. Brief Overview

- Hybrid vehicles, such as the Toyota Prius or the Ford Escape, combine batteries and an electric motor, along with a gasoline engine, to improve vehicle performance in city driving conditions and to reduce gasoline consumption.
- Plug-in hybrid vehicles are a more advanced version of today's hybrid vehicles. They involve larger batteries and the ability to charge those batteries overnight using an ordinary electric outlet.
- Unlike today's hybrids, plug-in hybrids are designed to be able to drive for extended periods solely on battery power, thus moving energy consumption from the gasoline tank to the electric grid (batteries are charged overnight from the grid) and emissions from the tailpipe to the power plant (where, in theory, they are more easily controlled).
- Plug-in hybrids could significantly reduce U.S. gasoline consumption because most daily trips would be powered by a battery. The potential for oil savings is related to the length of time, or the distance, that a plug-in hybrid can travel solely on battery power.
- President Bush, as part of his *Advanced Energy Initiative,* has established the goal of developing technology that would enable plug-in hybrids to travel up to 40 miles on battery power alone. Plug-in hybrids that could operate for 40 miles on an overnight charge from the electrical grid could offer significant oil savings because most Americans commute less than 40 miles a day. The electricity used to charge the batteries overnight would be generated from domestic sources (only three percent of the electricity used in the United States is generated from oil) and that electricity would primarily be consumed at night when demand is low.
- Plug-in hybrids could benefit consumers because of their greater fuel economy and the relatively low cost of energy from the electric grid. Fuel economy in hybrid vehicles is related to the degree to which engine load can be carried by the electric motor (powered by batteries). Because plug-in hybrids have large batteries and are designed to operate for an extended period on battery power alone, they offer the potential of significantly greater fuel economy. Some proponents of plug-in hybrids claim that consumers will be able to recharge their batteries overnight at gasoline-equivalent cost of $1 per gallon.[1]
- While plug-in hybrid vehicles offer many advantages, a number of technical barriers must be overcome to enable their development and widespread commercial application. Although specialty conversion kits are available (in very limited quantities and at high cost) to upgrade an ordinary hybrid to a plug-in hybrid, many component technologies, particularly battery technology, must be advanced before plug-in hybrids can be made available to consumers, at mass-market scale, and at reasonable cost and reliability. R&D is needed to increase the reliability and durability of batteries, to significantly extend their lifetimes, and to reduce their size and weight.
- In May 2006, Mr. Smith of Texas prepared a discussion draft of legislation to conduct research and development (R&D) on advanced plug-in hybrid vehicle technologies and to demonstrate plug-in hybrid vehicles so as to promote their commercial application in the consumer marketplace. (A section-by-section analysis of the bill is included later in this charter.)

5. Background

How would plug-in hybrid vehicles differ from today's hybrid vehicles? Plug-in hybrid vehicles would have a much bigger battery and motor, and thus could offset even more gasoline consumption than hybrids do by using more electric power. Unlike today's hybrid vehicles, the battery of a plug-in hybrid would be charged while parked using a standard 120-volt electrical outlet. (Additional technical information is available in the technical appendix to this charter.)

How would plug-in hybrid vehicles promote energy independence? Plug-in hybrids could greatly decrease the need for petroleum by shifting the energy supply for vehicles from the gasoline pump to the electrical grid. Since only three percent of petro-

[1] Plug-In Partners website. Date accessed—May 12, 2006. See *http://www.pluginpartners.org/plugInHybrids/economicBenefits.cfm*

leum is used to generate electricity (a figure unlikely to increase due to poor economics associated with electricity from oil), an expansion in plug-in hybrids would help decrease U.S. dependence on imported oil. Because of their greater ability to operate on electric power, plug-in hybrids have the potential for significantly greater fuel economy than currently-available hybrid vehicles. An entrepreneurial group in California (CalCars) has experimented with plug-in hybrids and claims to have achieved fuel economy in excess of 100 miles per gallon after converting a standard hybrid vehicle to a plug-in hybrid.

How would plug-in hybrid vehicles affect the grid? Plug-in hybrids typically would be used during the daytime, when people commute to work or when businesses are making deliveries, and charged overnight, when the grid is running well below its peak load. The increased demand for electricity during overnight charging also would provide a load leveling effect—idle generating capacity would be brought into productive use during off-peak hours. Allowing plants to operate with less variability and closer to optimum output could enhance the overall efficiency of the electrical system.

How would plug-in hybrid vehicles affect emissions? Plug-in hybrids shift much of the emissions from the tailpipe to the power plant. Proponents claim that the overall emissions level of the most common pollutants is lower from plug-in hybrids than from standard automobiles, even accounting for emissions at the power plant. The one exception is sulfur dioxide emissions in areas that utilize a great deal of coal-fired electricity.

Widespread use of plug-in hybrids would enable metropolitan areas suffering from high air pollution concentrations during morning and evening commutes to shift those emissions away from city centers and to nighttime hours. This shift would reduce the exposure of high population density areas to harmful ozone levels and other tailpipe pollutants. Greenhouse gas levels could also be reduced, depending on the mix of energy sources used to generate electricity.

What does the President's budget include for plug-in hybrid R&D? The President's fiscal year 2007 (FY07) budget submission requests $12 million for R&D on plug-in hybrid vehicles, including an increase of $6 million for R&D related to advanced battery development. The President's FY07 request also includes $51 million for R&D on related vehicle technologies, including advanced power electronics, simulation and validation, and vehicle test & evaluation.

Addition details on the difference between plug-in hybrids and today's hybrids, along with details on the technical barriers to developing mass-market plug-in hybrid vehicles, are given in the technical appendix (section 8) of this charter.

A description of Mr. Smith's discussion draft, as provided to the witnesses, is given below. The language describing the demonstration program in the discussion draft has been modified since it was sent to the witnesses.

6. Section-by-Section Description of the Discussion Draft

Sec. 1. Short Title.

The Plug-In Hybrid Electric Vehicle Act of 2006.

Sec. 2. Near-Term Vehicle Technology Program

a. Definitions.

Defines terms used in the text.

b. Program.

Requires the Secretary of Energy to carry out a program of research, development, demonstration, and commercial application for plug-in hybrid electric vehicles and electric drive transportation technology.

Requires the Secretary of Energy to ensure that the research program is designed to develop

- high capacity, high efficiency batteries with:
  - improved battery life, energy storage capacity, and power discharge;
  - enhanced manufacturability; and
  - the minimization of waste and hazardous material production throughout the entire value chain, including after the end of the useful life of the batteries
- high efficiency on-board and off-board charging components;
- high power drive train systems for passenger and commercial vehicles and for non-road equipment;

- control systems, power trains, and systems integration for all types of hybrid electric vehicles, including:
    - development of efficient cooling systems; and
    - research and development of control systems that minimize the emissions profile of plug-in hybrid drive systems
- a nationwide public awareness strategy for electric drive transportation technologies that provide teaching materials and support for university education focused on electric drive systems and component engineering.

c. Goals.

Requires the Secretary of Energy to ensure that the program develops projects, in partnership with industry and institutions of higher education, which are focused on:

- innovative electric drive technology developed in the United States;
- growth of employment in the United States in electric drive design and manufacturing;
- clarification of the plug-in hybrid potential through fleet demonstrations; and
- acceleration of fuel cell commercial application through comprehensive development and demonstration of electric drive technology systems.

d. Demonstration and Commercial Application Program.

Requires the Secretary of Energy to develop a program of demonstration and commercial application for plug-in hybrid electric vehicles and flexible fuel plug-in hybrid electric vehicles.

Requires the Secretary of Energy to award grants under this program on a competitive basis, but give preference to applications that are matched with state or local funds.

Requires that grants awarded by the Secretary do not exceed the annual maximum per-vehicle amounts as follows:

Annual Maximum Grant per Vehicle

FY07 – FY09	FY10 – FY12	FY13	FY14	FY15	FY16
$10,000	$8,000	$6,000	$3,000	$2,000	$1,000

e. Merit based federal investments.

Requires the Department of Energy to ensure that the funding for the activities in this section are awarded consistent with the merit based guidelines for federal investments established in the *Energy Policy Act of 2005* (EPACT) (P.L. 109–58).

f. Authorization of Appropriations.

Authorizes appropriations to the Secretary of Energy of $200 million for each of fiscal years 2007 through 2016 to carry out the program of research, development, demonstration, and commercial application for plug-in hybrid electric vehicles and electric drive transportation technology.

Authorizes appropriations to the Secretary of Energy of $50 million for each of fiscal years 2007 through 2016 to carry out the demonstration of plug-in hybrid electric vehicles and flexible-fuel plug-in hybrid electric vehicles.

Sec. 3. Lightweight Materials Research & Development.

a. In General.

Requires the Secretary of Energy to create a lightweight materials research and development program. The program will focus on materials (for both light and heavy duty vehicles) that will reduce vehicle weight and increase fuel economy while maintaining safety. In addition, the program will investigate ways to reduce the cost and enhance the manufacturability of lightweight materials used in making vehicles.

b. Authorization of Appropriations.

Authorizes appropriations to the Secretary of Energy of $50 million for each of fiscal years 2007 through 2012 to carry out this section.

7. Witness Questions

In the letters inviting them to the hearing, each of the witnesses was asked to address the following questions in his testimony:

- What major research, development, and demonstration work remains on plug-in hybrid electric vehicle technologies? How should this work be prioritized?
- What are the largest obstacles facing the widespread commercialization of plug-in hybrid electric vehicles and what steps need to be taken to address these hurdles? (batteries, infrastructure, consumer preference, automotive inertia, cost-competitiveness, etc.)
- How does the Federal Government support the development of plug-in hybrid electric vehicle technologies? What can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles?
- Does the discussion draft address the most significant technical barriers to the widespread adoption of plug-in hybrid electric vehicles?

8. Technical Appendix

What are the technological differences between plug-in hybrid vehicles and the hybrid vehicles on the road today?

The hybrid vehicles on the road today leverage the battery and electric motor at certain peak demand points during the drive cycle of the vehicle. The battery, generally nickel metal hydride (NiMH) technology, is replenished by occasionally transferring energy from the engine as well as from recovering energy expended in braking the vehicle (i.e., regenerative braking). The battery maintains a state of charge within a fairly narrow band, never gaining or losing a great deal of energy; this is known as shallow cycling or a "sustained charge" approach. Using the energy from NiMH battery to avoid gasoline consumption helps hybrid vehicles achieve increased fuel economy.

Plug-in hybrid vehicles take advantage of the same fuel economy principle, only the goal is to use a better battery to avoid even greater amounts of gasoline. Lithium-ion (Li-ion) battery technology has been identified as the most promising candidate for plug-in hybrid electric vehicles. Li-ion batteries have greater energy density than NiMH batteries and greater power discharge, characteristics that would allow a vehicle to travel further using less gasoline and offer better performance than one with a NiMH battery.

In addition, plug-in hybrid electric vehicles could offer long ranges of electric-only operation (also known as a "ZEV" range or Zero Emissions Vehicle range). This attribute is particularly desirable in congested metropolitan areas. If today's hybrid vehicles with a NiMH battery were available with an electric-only operation mode, they would be capable of only a one-two mile ZEV range. In comparison, experts familiar with battery technology claim that Li-ion batteries could achieve ZEV ranges of 20, 40, or even 60 miles.

It is not clear whether plug-in hybrid vehicles would be manufactured with an option of driving in "electric-only" mode. Regardless, the overwhelming majority of the energy used in city driving would stem from the battery, given that the engine is inefficient in stop-and-go traffic. Thus, the long ZEV range figures associated with Li-ion batteries not only indicate the large quantity of electrical energy they contain, but also the potential to drive lengthy distances under city conditions using mostly electrical energy. With Americans commuting an average of 20–30 miles roundtrip each day, the plug-in hybrid vehicle with a Li-ion battery could greatly reduce petroleum consumption.

Why don't we use lithium-ion battery technology today given its benefits?

Li-ion batteries are not a new technology. They are used in cell phones and laptop computers. Scaling up Li-ion batteries for use in automobiles, however, is new territory and presents new challenges. Experts in the field estimate that the cost of Li-ion batteries is two to four times above the level needed to be commercially viable. Cost reductions are needed in the areas of raw materials and processing, as well as cell and module packaging.

In addition, it is not clear if Li-ion batteries are capable of lasting 15 years, the average life of a vehicle. This issue is compounded by the fact that plug-in hybrid vehicles would use deep cycling, which shortens the life of the battery, over the course of its drive cycle. Unlike the sustained charge approach used in today's hybrid vehicles, the profile of plug-in hybrid is much different. Plug-in hybrids would start the day at nearly 100 percent state of charge (SOC), having been charged overnight. To minimize use of gasoline, the battery would be depleted over the course of the day until the SOC reached about 20 percent; fully depleting the battery each day would severely limit its lifetime. At a SOC of about 20 percent, the plug-in hybrid would act like a hybrid vehicle and proceed with a "sustained charge" approach until the vehicle could be fully recharged again. Further testing is needed to determine whether Li-ion batteries could last the life of the vehicle under this combined deep/shallow cycling.

Additional R&D is needed in other areas as well. There is uncertainly about the ability of Li-ion batteries to handle abuse and improper maintenance, such as crushing the battery or overcharging. Current Li-ion batteries require mechanical and electronic devices for protection against these abuses. Likewise, more work is needed to enhance Li-ion technology in colder temperatures. Under these conditions, Li-ion demonstrates a reduction in its ability to discharge power and its lack of tolerance for handling surges from regenerative braking. In addition, thermal management issues will need to be addressed, as long periods of continuous battery use can lead to a build up of heat. There are existing technologies that can be used that tolerate higher temperatures, but they would increase the cost of the battery.

What challenges inhibit the near-term introduction of plug-in hybrid electric vehicles?

As noted earlier, the battery technology for plug-in hybrids is not yet cost-competitive. Since the battery represents a large proportion of the incremental cost of plug-in hybrid over a conventional vehicle, R&D will likely be focused here. The issue of cost is further complicated by the deep discharges that are used in plug-in hybrids. If batteries do not last the lifetime of the vehicle, replacement batteries will make the plug-in hybrids even less attractive from a cost standpoint. The cost of a plug-in hybrid passenger vehicle with a 20 mile ZEV is approximately $4,500 to $6,100 more than a conventional vehicle of comparable size, according to a 2002 report by the Electric Power Research Institute.

Major manufacturers of today's hybrids have exerted a great deal of effort to educate consumers that hybrid vehicles differ from all-electric vehicles of the past in that they do not need to be plugged in. The plug-in hybrid would be a new technology, also using the word "hybrid" in its label, but will require customers to plug into an electrical outlet in their home or garage. Even if customers understand this distinction, they may not be willing or able to conform to a new norm. Plug-in hybrids may provide the convenience of reducing the number of trips to gas stations, but consumers must become comfortable with and accustomed to the idea of plugging in their vehicle. Other customers may be interested in plug-in hybrids, but currently may live in a dwelling without a plug-in infrastructure or otherwise not conducive to vehicle charging. Responding to all of these challenges will likely require outreach and education.

Chairwoman BIGGERT. The hearing of the Energy Subcommittee of Science will come to order.

Before we begin, I ask unanimous consent that my colleague, Mr. Smith from Texas, be allowed to join the Energy Subcommittee for this hearing. If there are no objections, so ordered.

I would like to welcome everyone to this Energy Subcommittee hearing on the many potential contributions that plug-in hybrid electric vehicles could make to our energy security.

Last year, if somebody had asked me if I had any plans to chair a hearing on plug-in hybrids in 2006, my response would have been: "What is a plug-in hybrid?" Yet here we are today examining a discussion draft of legislation that will be introduced by a senior Member of this committee, Congressman Lamar Smith, to promote the development and use of plug-in hybrids. I want to thank Mr. Smith for introducing me to plug-in hybrids.

What is so special about a plug-in hybrid? Well, in a nutshell, average Americans who drive their cars or trucks between 25 and 30 miles a day could complete their commute and run some errands without burning a drop of gasoline. That is good for energy security, not to mention the pocketbook.

Furthermore, the technology to make this happen is an improvement upon existing technology in the market today. Unlike hydrogen fuel cells, which are still very much in the research and development stage, and by some estimates, still 20 years from reaching the market, conventional or traditional hybrids can be found in dealership lots across the country and are growing in popularity. With research, I hope this transition from conventional hybrids to plug-in hybrids can proceed quickly.

And there is nothing like a $3 gallon of gasoline to help get us thinking about new and creative ways to diversify the fuel supply and use anything besides gasoline to power our vehicles. As I have said many times before, I do not believe that there is a single solution to our energy problems. Plug-in hybrids would allow us to power our cars with clean energy, including from renewable sources, such as solar and wind. They can also be fueled by other clean and abundant sources, like nuclear and even coal, preferably from power plants employing advanced clean coal technologies that I hope will soon be the norm.

The fact of the matter is that all Americans, including those in my suburban Chicago district, want to hop into their cars and go. Very few care what makes their car go. They simply want it to be inexpensive and easy to get. Again, the consumer is pointing us in the right direction. We should be working towards cars that can run on whatever energy source is available at the lowest cost: be it electricity, gasoline, biofuel, or some combination of these.

That brings me to my final point on the potential benefits of the plug-in hybrid. They do not require a whole new "refueling" infrastructure. To think that you could pull into your garage at the end of the day and "fill 'er up" just by plugging your car into a regular 110-volt socket in the garage is very appealing. Imagine the convenience of recharging your car just as you recharge your cell phone, blackberry, or laptop every evening, by simply plugging it in. The next morning, unplug it, and you are ready to go.

That is not to say there aren't challenges to realizing the potential benefits of plug-in hybrid electric vehicles. Our purpose here today is to identify the most significant obstacles facing the widespread commercial availability of these vehicles. Are there technical or cost-competitiveness issues with important components, such as batteries or power electronics? Do consumer preferences or auto industry inertia present high hurdles? Our witnesses today can help us understand what additional steps the Federal Government can take to address these barriers and accelerate the development and deployment of plug-in hybrids.

And I, again, would like to thank Mr. Smith for bringing this to our attention.

[The prepared statement of Chairman Biggert follows:]

PREPARED STATEMENT OF CHAIRMAN JUDY BIGGERT

Good morning. On behalf of Ranking Member Honda and myself, I want to welcome everyone to this Energy Subcommittee hearing. We are examining the potential contribution that plug-in hybrid electric vehicles can make to the energy security of this nation. We also want to obtain feedback on a discussion draft of legislation Representative Lamar Smith has developed to promote the use of plug-in hybrids.

Needless to say, energy security is a rather timely issue. Americans consume more than 20 million barrels of oil products every day, and 40 percent of that goes to fueling our cars and trucks. By the year 2020, more than sixty percent of our oil will come from foreign sources. If that comes true, we will face real and significant challenges to our efforts to maintain our security and fight terrorism. A major interruption in the supply chain, whether accidental—as we saw with Hurricanes Katrina and Rita—or intentional could have enormous impacts on our economy.

As our economy grows and our population prospers, our demand for oil and other sources of energy will only increase. But continuing on a business as usual path is risky not only for our security and for our economy but also for our environment. The carbon dioxide, particulates and ozone-forming emissions from cars and trucks contribute to both global climate change and localized urban air pollution. Not only is urban air pollution correlated with high levels of asthma, lung cancer and other devastating illnesses, but it reduces the quality of life for those who live in and around cities. I can assure you none of my constituents are demanding more smog!

As I have said many times before, I do not believe that there is a single solution to our energy problems. We need to use the resources we do have more wisely, and we need to expand domestic sources of clean energy, including both renewable sources, such as solar and wind, *and* nuclear energy.

Some technologies that we hope will be a part of the solution—such as hydrogen fuel cells—are still largely in the research and development stage. They are likely to be many years off. There are other technologies that may be economically deployed on a large scale in the near term. We are looking to you, our witnesses, to tell us whether you believe plug-in hybrid vehicles are in this category.

Personally, I hope they are. I find the concept of plug-in hybrids fascinating. To think that I could pull into my garage at the end of the day and "fill 'er up" just by plugging my car in to a socket is very attractive. Imagine how convenient that would be: Recharge my car, walk in the house, recharge my cell phone. The next morning, unplug and be ready to go. I'd only have to go to the gas station before road trips!

I also think it is important—exciting is probably not the word—that plug-in hybrids offer the chance to diversify the fuel supply for our transportation sector. Plug-in hybrids would allow us to power our cars with coal—I hope that will soon be clean coal—nuclear or some combination of renewable resources. Here in D.C., we have the oil lobby, the switch grass lobby, the corn lobby, the coal lobby, the wind and solar lobby. In my district in suburban Chicago, my constituents want to hop in their cars and go. Very few of them care what makes their car go. Consumers may be pointing us in the right direction. We should be working towards cars that can run on what ever energy source is available at the lowest cost: be it electricity, gasoline, or some biofuel.

In our hearing today, we will examine the major research and development questions facing plug-in hybrid technologies and try to understand how this work should be prioritized. We want to be able to identify the most significant obstacles facing the widespread commercial availability of plug-in hybrid electric vehicles. Are there technical or cost-competitiveness issues with important components, such as batteries or power electronics? Do we lack essential infrastructure? Do consumer preferences or auto industry inertia present high hurdles? Our witnesses today can help us understand what additional steps the Federal Government can take to address these barriers.

I don't want to presume to speak for my colleagues on this subcommittee, but I think all of us would like to see the development and deployment of plug-in hybrid electric vehicles accelerated. I know my constituents think plug-in hybrids sound exciting when they hear about the technology. They want to know when they will be able to buy them, and—to be honest—so do we.

I would like to thank each of our witnesses for taking the time to educate us about this important subject and to comment upon our draft legislation. I would like to thank Representative Smith of Texas for the leadership he has taken on this issue. We greatly appreciate the opportunity to provide input on his draft legislation, and we hope to see it move expeditiously towards enactment.

Finally, I would like to mention that at the conclusion of our hearing, we have an opportunity to see two plug-in hybrids by CalCars at noon at the corner of New Jersey Avenue and C Street Southeast, courtesy of Representatives Jack Kingston and Elliot Engel. Begging everyone's apologies, this really is a technology right around the corner.

And now, I want to welcome my colleague Mr. Honda and recognize him for his opening remarks.

Chairwoman BIGGERT. And I would recognize the Ranking Member, Mr. Honda, for his opening statement.

But before I recognize him, I just want to make a quick announcement and recognize a couple of folks from CalCars who have a special treat for us this morning. At the conclusion of our hearing, we have an opportunity to see two plug-in hybrids by CalCars on the corner of New Jersey Avenue and C Street Southeast, courtesy of Congressman Jack Kingston and Congressman Eliot Engel. And begging everyone's apology, this really is a technology right around the corner, so I hope everyone here will join us. If you would like to stand up and—so with that, I recognize Mr. Honda for five minutes.

Mr. HONDA. Thank you, Madame Chairwoman.

I guess that infrastructure, if you don't have one, you can congratulate yourself for not having one.

I want to thank the Chairwoman for holding this important hearing today and thank all of our witnesses for being here to share their expertise with us. You have come from all across the country. And let me just say to the Honda dealer—the Honda folks that there is no relationship, and when I mentioned Prius, it is only because they had the hybrid out, the first one. I was looking for one, and then you came right after that.

As you may know, I do drive a Prius hybrid, and I have asked my poor staffers to hook up a server cell to my Prius, because when I left my car at the airport for a week or so, the starting battery would die out, and I couldn't figure it out, and so I decided to try to add a little bit more technology and have a trickle charge hooked up to the back of my car.

So I think it is fair to say that you can count me in among the converted on this technology.

As gasoline prices have skyrocketed in recent weeks, there seems to be more of a sentiment, fortunately, among us policy-makers to support the development of more efficient vehicles. Consequently, 75 percent of the energy consumed in transportation is provided by petroleum. Of that 75 percent in 2004, nearly 63 percent came from foreign sources. The trend indicates that this will only get worse if the United States does not make significant strides towards reducing consumption in the transportation sector.

Small steps can make a big difference. A 10 percent reduction in energy use from cars and light trucks would result in a savings of nearly—approximately 750,000 barrels of petroleum per day. Today's electric hybrids are a step in the right direction to reducing our dependence on petroleum with the Prius traveling about 42 to 50 miles per gallon of gasoline. But because the only source of energy for today's hybrids is gasoline, some of that energy must go into charging the batteries, limiting the overall vehicle efficiency. I am excited about the prospect of plug-in hybrids because they are able to store more electrical energy on-board, meaning that they can travel further on their initial charge than the gasoline carried on-board.

Plug-ins can also reduce the overall amount of pollution, because the power plants are more efficient at controlling combustion emissions than the vehicles are.

One question I do have, however, is that what impacts would—plug-in hybrid use will have on the Nation's electricity grid if we are successful in convincing hundreds of millions of Americans to purchase and use plug-in vehicles. And that is a question. In California, we don't have a whole lot of electricity to spare. Advocates for plug-in hybrids say that we will recharge these cars at night when most of the demand is baseload, so it won't be a problem. But if we get enough people to adopt plug-in hybrid technology, will we exceed the capacity of a baseload generation and need to use more power plants, ones that use natural gas as fuel? If so, then I fear we would just be shifting our addiction from one petrochemical to another.

Hopefully, the witnesses will address this in their testimony or in the question-and-answer period.

Now please let me apologize in advance. I may need to leave early to go to a markup in another committee, but rest assured that I share the Chairwoman's enthusiasm for this technology, and I look forward to hearing the testimony. Again, I thank the witnesses for being here, for your knowledge, and for your enthusiasm.

I yield back.

[The prepared statement of Mr. Honda follows:]

PREPARED STATEMENT OF REPRESENTATIVE MICHAEL M. HONDA

I thank the Chairwoman for holding this important hearing today, and thank all of our witnesses for being here to share their expertise with us.

As you may know, I drive a Prius hybrid, and I've asked my poor staffer about hooking up a solar cell to keep the starting battery charged for those times when I've left the car at the airport for a few weeks. So I think it's fair to say that you can count me among the converted on this technology.

As gasoline prices have skyrocketed in recent weeks, there seems to more sentiment among policy-makers to support the development of more efficient vehicles.

Approximately 75 percent of the energy consumed in the transportation is provided by petroleum. Of that 75 percent, in 2004 nearly 63 percent came from foreign sources. The trend line indicates that this will only get worse if the U.S. does not make significant strides towards reducing consumption in the transportation sector.

Small steps can make a big difference. A 10 percent reduction in energy use from cars and light trucks would result in the savings of nearly 750,000 barrels of petroleum per day.

Today's electric hybrids are a step in the right direction to reducing our dependence on petroleum, with the Prius traveling about 50 miles per gallon of gasoline. But because the only *source* of energy for today's hybrids is the gasoline, some of that energy must go into charging the batteries, limiting the overall vehicle efficiency.

I'm excited by the prospect of plug-in hybrids because they are able to store more electrical energy on-board, meaning they can travel farther on their initial charge and the gasoline carried on board. Plug-ins can also reduce the overall amount of pollution because power plants are more efficient at controlling combustion emissions than vehicles are.

One question I do have, however, is what impact plug-in hybrid use will have on our nation's electricity grid if we are successful in convincing hundreds of millions of Americans to purchase and use plug-in hybrid vehicles. In California, we don't have a whole lot of electricity to spare.

Advocates for plug-in hybrids say that we will recharge these cars at night, when most of the demand is base load, so it won't be a problem. But if we get enough people to adopt plug-in hybrid technology, will we exceed the capacity of the base load generation and need to use more power plants, ones that use natural gas as a fuel?

If so, then I fear we would just be shifting our addiction from one petrochemical to another. Hopefully the witnesses will address this in their testimony or in the Question and Answer period.

I share the Chairwoman's enthusiasm for this technology, and I look forward to hearing the testimony. Thanks again to the witnesses for being here, and I yield back the balance of my time.

Chairwoman BIGGERT. Thank you, Mr. Honda.

Any additional opening statements submitted by Members may be added to the record.

[The prepared statement by Mr. Costello follows:]

PREPARED STATEMENT OF REPRESENTATIVE JERRY F. COSTELLO

Good morning. I want to thank the witnesses for appearing before our committee to discuss a draft of legislation sponsored by Representative Smith, to promote research and development (R&D) on plug-in hybrid electric vehicles.

Plug-in hybrid electric vehicles are hybrid cars with an added battery. As the term suggests, plug-in hybrids—which look and perform much like "regular" cars—can be plugged in each night at home, or during the workday at a parking garage, and charged. Plug-ins run on the stored energy for much of a typical day's driving—depending on the size of the battery up to 60 miles per charge. When the charge is used up, the car automatically keeps running on the fuel in the fuel tank. Therefore, plug-in hybrids can deliver dramatic improvements in fuel economy by driving their first 25 to 50 miles on clean renewable electric fuel for about one-fourth the price of gasoline before turning on the combustion engine. Many experts contend that widespread use of plug-in hybrids could significantly contribute to the reduction of emissions and dependency on foreign oil.

While hybrid-plug in cars could benefit consumers because of their greater fuel economy and the relatively low cost of energy from the electric grid, I am interested in learning what are the largest obstacles facing the widespread commercialization of plug-in hybrid electric vehicles and what steps need to be taken to address these hurdles. In addition, I look forward to hearing from the witnesses on their assessment of the discussion draft. Thank you.

[The prepared statement by Ms. Johnson follows:]

PREPARED STATEMENT OF REPRESENTATIVE EDDIE BERNICE JOHNSON

Thank you, Madam Chair and Ranking Member. We have a number of witnesses here today to discuss the feasibility of plug-in hybrid vehicles and how they can help America lessen its dependence on foreign fossil fuels.

I would like to provide a special Texas welcome to Mr. Roger Duncan, who is the Deputy General Manager of Austin Energy and a fellow Texan.

Madam Chair, I am pleased to see this Subcommittee focused on the issue of energy as it relates to this nation's transportation needs.

Gas prices continue to escalate, especially in Texas. Pair that with the issue of urban sprawl, what we're seeing is an energy crisis that experts predict will affect American's spending and vacation plans this coming summer.

Congress must provide strong leadership to spur research and development in the areas of energy efficiency and alternative fuels.

Again, I am pleased we are having this discussion today and welcome the witnesses.

Thank you, Madam Chair. I yield back.

[The prepared statement of Ms. Jackson Lee follows:]

PREPARED STATEMENT OF REPRESENTATIVE SHEILA JACKSON LEE

Madame Chairman, I appreciate the opportunity today to explore the development and relevance of plug-in hybrid technology, and to discuss the merits of legislation that promotes research and development of plug-in hybrid electric vehicles.

As we are all aware, this country faces both short-term and long-term energy crises, most immediately evidenced by gas prices that creep higher every day. Our dependence on oil, and the negative consequences inherent in this dependency, is well documented and one of the few policy issues over which there is no partisan dispute.

The plug-in technology combines a significantly more powerful battery with gasoline fuel, with the added benefit of being able to plug in the vehicle to an electricity outlet and recharge the battery. At this time, the batteries last for approximately 20 to 30 miles, which is, coincidentally, the average American commuting distance. Imagine spending money only to fuel long-distance drives, and recharging your car completely every night!

The fuel economy and energy efficiency of plug-in hybrid vehicles could benefit consumers and the economy as a whole. The legislation directs the Secretary of Energy to pursue further research on technology such as high capacity and high efficiency batteries, as well as research into lightweight materials, which can also affect the efficiency of the car.

One of the many reasons I enjoy sitting on this subcommittee is the frequent exposure and discovery of innovative policy options. I am so pleased today to have the opportunity to discuss one consumer option that appears feasible and practical, and that is likely to prove its worth in the marketplace. I applaud all of the witnesses for their efforts in making electric vehicles even more of a reality.

Thank you Madame Chairman, and I yield back the remainder of my time.

Chairwoman BIGGERT. And at this time, I would like to introduce our witnesses and thank you all for coming this morning.

First, we have Dr. Andy Frank. He is a Professor in the Mechanical and Aeronautical Engineering Department at the University of California, Davis, and the Director of the UC Davis Hybrid Electric Vehicle Research Center. Welcome.

I would now like to recognize my colleague, Mr. Smith, to introduce the next witness.

Mr. SMITH. I thank you, Madame Chairman.

First of all, let me thank you for having this hearing on the general subject of hybrid vehicles and more specifically on the discussion draft of the bill *"The Plug-In Hybrid Electric Vehicle Act of 2006,"* which I expect to introduce in a few days with your good support as an original co-sponsor, and I thank you for that.

I would like to introduce Roger Duncan, who is from my home state of Texas and also from Austin, which is a city that is in my Congressional district. He is here to share his knowledge of plug-in hybrid electric technology.

Mr. Duncan has been a leader in energy conservation and environmental policy for over 20 years. He is the Deputy General Manger of Austin Energy, which is the Nation's tenth largest community-owned electric utility.

Since joining the City of Austin's management staff in 1989, he has overseen the development and implementation of water and air quality programs, environmental reviews, and energy and water conservation programs.

Prior to his service in city management, he served four years as a city council member. So, Madame Chair, I think we should probably call him honorable today, among other terms.

He also serves as a board member of the Electric Drive Transportation Association and is the campaign coordinator for Plug-In Partners.

He has been recognized by BusinessWeek Magazine as one of the 20 top leaders of the decade in the effort to reduce gases that cause global warming.

So I am pleased to introduce him today to our fellow colleagues on this committee, but I also have to say, Madame Chairman, that because of a markup on the Homeland Security Committee on which I also sit, I am going to need to leave after his testimony, but I do intend to stay at least for that amount of time.

And thank you again for the privilege of introducing a constituent.

Chairwoman BIGGERT. Thank you.

It must be Wednesday morning. We seem to have a lot of hearings every Wednesday. We are all trying to be in three places at once.

Next, Dr. Duvall, is a Technology Development Manger for Electric Transportation & Specialty Vehicles in the Electric Power Research Institute's, or EPRI, Science & Technology Division. He currently oversees EPRI's Grid-Connected Hybrid Electric Vehicle Working Group and is EPRI's technical lead for the DaimlerChrysler-EPRI Plug-in Hybrid Electric Sprinter Van Program. Welcome.

And next we have Dr. John German. He is a Manager of Environmental and Energy Analyses for American Honda Motor Company. Mr. German is the author of a variety of technical papers and a book on hybrid gasoline-electric vehicles published by the Society of Automotive Engineers. Welcome, Mr. German.

Mr. Gordon, our Ranking Member on the Science Committee, is here to introduce the next witness.

Mr. GORDON. Thank you, Madame Chair.

I am pleased to have the opportunity to introduce one of my home boys. Dr. Cliff Ricketts is one of the most innovative individuals I know. He has held the land speed record for hydrogen vehicles at the Bonneville Salt Flats for 15 years and has experimented with a variety of electric hybrid and biodiesel fuel vehicles in his 30 years at my alma mater, Middle Tennessee State University. He has also worked with solar energy and has a 10-kilowatt solar unit that banks electricity with the local electric supplier to charge his own hybrid vehicle and hybrid—and produce hydrogen from water through electrolysis to operate his own internal combustion automobile. The only two sources of energy that runs his vehicles are sun and water.

But I think the importance of Dr. Ricketts being here today is he represents a cadre of hundreds, maybe thousands, of garage innovators all around this country that are working with virtually no resources but only their own innovation. And it is my hope that we are going to be able to find them ways to get the resources so that we can spark a new technology here. I am convinced that there are Orville and Wilbur Wrights in our midst, and we just have to go out and find them. And Dr. Ricketts, I think, is at the head of that stream.

So thank you, Dr. Ricketts, for being here today.

Chairwoman BIGGERT. Thank you, Mr. Gordon.

And last, but not least, we have Dr. Dan Santini. He is a senior economist in the Energy Systems Division of Argonne National Laboratory's Center for Transportation Research as well as the former Chair of the Alternative Fuels Committee of the National Academy of Sciences' Transportation Research Board. Thank you very much for being here.

As I am sure the witnesses know, spoken testimony will be limited to five minutes each, after which the Members will have five minutes each to ask questions. So try and keep somewhat near to that limit. I know you have a lot to say, and I really look forward to hearing from you.

And we will begin with Dr. Frank.

Dr. Frank, could you turn on the microphone, please, and pull it a little bit closer?

STATEMENT OF DR. ANDREW A. FRANK, PROFESSOR, MECHANICAL AND AERONAUTICAL ENGINEERING DEPARTMENT, UNIVERSITY OF CALIFORNIA, DAVIS

Dr. FRANK. Okay. Here we go.

I am going to waste a minute of my precious time right here, but I will play this little clip from——

[Video.]

Okay. Now I am going to address some questions that I think Mr. Honda had just started, but here are some questions.

What major R&D work remains for plug-in hybrids technology and what needs to be prioritized?

I think the most important thing is: a lot of the R&D has been done by many of us sitting here at the table, but the most important thing is it is not ready for production. Pre-production vehicles and demonstrations are really needed. And we have got to develop a supply chain. There are pieces of the supply chain not completed, and that is one of the reasons why car companies say, "Well, we can't put these in production tomorrow."

But in terms of the priorities for a demo fleet, I think we would have to focus on the most important, the mid-sized, high-volume car and then the minivan and small SUVs. I think Ford has already started that. And we need to go to compact cars, like Prius. But we have to convert these to plug-ins.

Finally, the objective is to obtain feedback from customers and the manufacturing of the structure with the supply chain development, and then, of course, how much are we going to charge for these.

And then, most important is to integrate with the electric utilities, and Dr. Duvall will talk about that and what we should do.

But beyond the utilities, we need to consider wind and solar.

So do the feds support plug-in hybrids now? Well, we have had some support in the past, but my support has primarily come from student competitions, surprisingly enough, from the U.S. DOE, so I have to thank people for that. But it is really, and as I think the chairperson said this morning, they didn't hear about it last year.

Anyway, government support is needed today to build a fleet of, I think, 100 advanced, fully-engineered, plug-in hybrids just to demonstrate.

But the—one of the big issues is electric range. How far should these things go? Ten or sixty miles? What I have done is I have demonstrated that 60 miles is possible, but it may not be economically feasible. So OAMs are talking about that.

How much is it going to cost? Well, I don't know, but I think $50 million or so would get us started.

Convincing the oil companies—and what technical and social barriers are needed in convincing the auto and oil companies? You know, when you introduce these to the oil companies, they say, "You mean, you want to support something that is going to reduce the use of oil? That doesn't help our business." But in actual fact, it does. And the reason why is oil is a world market, and what oil we don't use in this country at a low cost will sell in the world market at a higher cost. So they will make more money rather than less. So it will—it behooves them to support this as well. And I know they haven't supported it in the past.

Auto companies, it is the same thing. If we, in our American auto companies, don't do something, foreign car companies will jump in immediately.

Ethanol. You know, the problem with ethanol is—we have cars that will burn ethanol, but we don't have an ethanol—we don't have an infrastructure to make ethanol. With a plug-in hybrid, we have infrastructure to—for electricity, but we don't have cars that use electricity. So what we really need to do is to marry these two concepts with the largest and quickest impact on oil reduction.

Use of plug-in hybrids to integrate rooftop solar and wind. I am not talking about big solar and wind, in other words, vehicle home office systems with rooftop solar can be all integrated. And what this will do is create new industries and jobs for Americans. And so anyway—and it will improve and move us towards a zero CO_2 emission society.

What is, as pointed out by the Chairperson, the most important thing is the cost of fuel. Fuel using electricity—using gasoline is about 15 cents per mile, but using electricity from the power plants is around three cents per mile. So you know, that is a major difference. Of course, using solar, you drive that even—down lower. What we don't want to do is step back in technology.

What are our technical and social barriers to the widespread adoption to PHEVs? We have an acceptance of home fueling, and I—by the way, you can't just plug these things into any old plug. You really need to have properly installed electric plugs in garages and so on. You see, the City of Davis has already passed an ordinance that every garage, new construction garage, has to have an EV-charging plug in the garage, so that is the kind of thing that has to be done.

We change our habits a little bit, because, as you point out, you plug it into the house and the most important thing is by fueling at home, you reduce your trips to the gas station from 35 times a year to about five times a year.

And for the electric grid, on the electric grid size, you really—you know, there is always the question that Mr. Honda pointed out.

Okay, what is going to happen to the grid? We have all of these hundreds of millions of cars plugged in. Eventually, we are going to have to go to something like the grid-wise system of the U.S. DOE where you only get a charge when the power company has it.

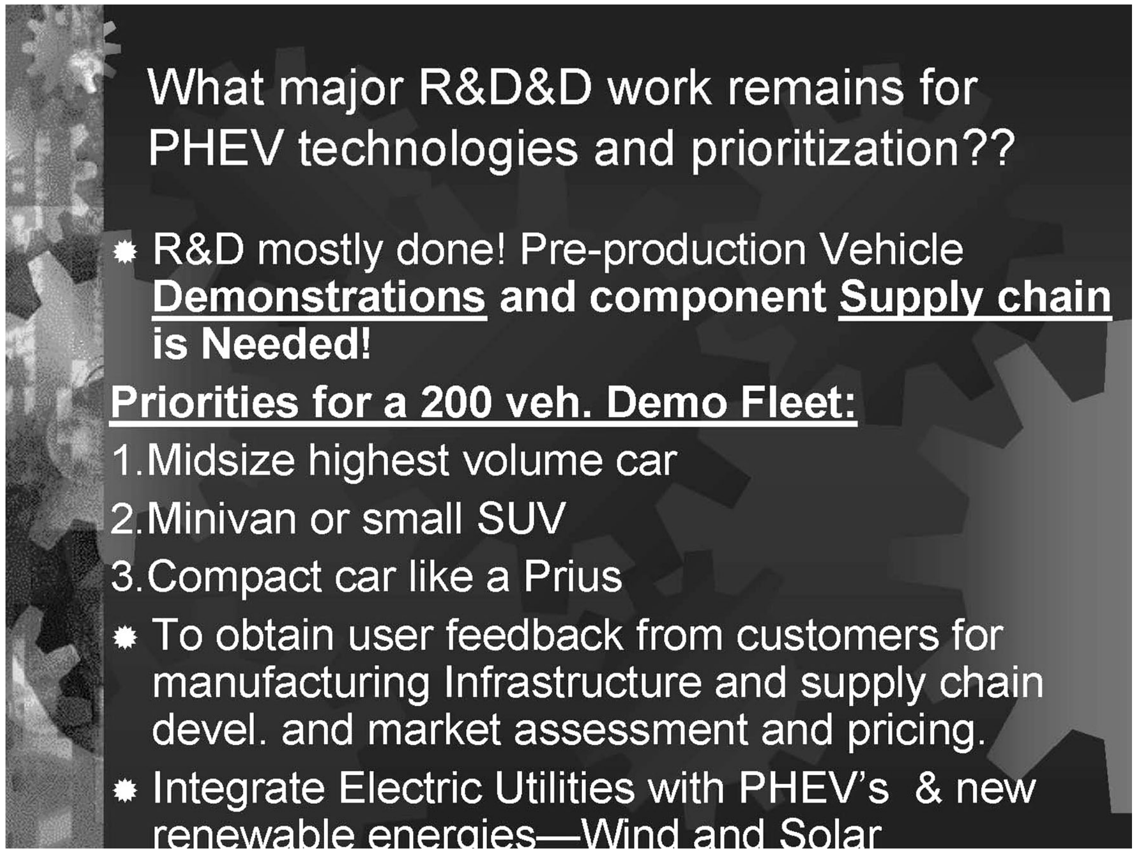
All right. So I think—am I running out of five minutes? Yeah. Okay. I will skip to the conclusion here.

I made this chart here, which shows the gasoline—gallons of gasoline saved per year for all electric ranges, ranging from zero range, so that is a regular hybrid, up to 40 miles. So when the President said all electric cars—plug-in hybrids with 40 miles range is kind of an optimum, he was right. Forty miles—beyond forty miles of all electric range, there isn't much gain, because you don't save much more gasoline after that.

Okay. Conclusions. R&D for plug-in hybrids has been done and ready for pre-production. We need 25 to 50 pre-production, completely engineered, properly integrated systems on existing cars to show that mass manufacturing can be done. And we need standards for design and tests by SAE and EPA and CARB, because at this current time, the standards for testing cars don't apply to plug-in hybrids. It is very important to redevelop that. And then finally, we need to integrate plug-in hybrids with small solar, wind, and ethanol and move towards—move the United States towards zero oil, coal, and CO_2. In the end, we can end up with an improved lifestyle and a much more energy-efficient society without any change in infrastructure.

[The prepared statement of Dr. Frank follows:]


The Plug-In HEV (PHEV) to reduce US dependency on oil and coal for both stationary and transportation energy--Testimony for US House Science/Energy Committee
5/17/06
Prof Andrew A. Frank
Director Hybrid Electric Vehicle Center
Dept of Mech. Aero. Eng
University of Calif.-Davis
Tel. 530 752 8120
Cell 530 902 4069
Email aafrank@ucdavis.edu
9 out of 1() Americans agree


What major R&D&D work remains for PHEV technologies and prioritization??
R&D mostly done! Pre-production Vehicle Demonstrations and component Supply chain is Needed!
Priorities for a 200 veh. Demo Fleet:
1.Midsize highest volume car
2.Minivan or small SUV
3.Compact car like a Prius
To obtain user feedback from customers for manufacturing Infrastructure and supply chain devel. and market assessment and pricing.
Integrate Electric Utilities with PHEV's & new renewable energies—Wind and Solar

What are the largest obstacles preventing widespread commercial applications & steps needed to -- Ameliorate?

- Automotive and Oil industry **Inertia**.--Demo. Vehicles
- Concept Value Judgment--PHEV is more than transportation-integrates with electric system, Therefore worth more!
- Battery life and Power electronics costs--supply chain development.
- Sealed and durable high voltage systems--Demo. and development.
- Need for New National Testing Standards for evaluation of energy use and safety procedures by USEPA, National Electric Code, UL, etc.

Do the Fed's support PHEV now? What can the Fed's do to accelerate production development of PHEV's

- Some past support from DARPA and Student Competitions (DOE) used for R&D by UCDavis—The only one in the country!
- Gov. support needed **today** to build a fleet of 200 **<u>advanced</u>** PHEV's with all electric ranges from 10 to 60 miles on three of the most popular platforms with one or two of the American OEM's in 2 to 3 years, and develop the supply chain—EDI is set up to do this!
- Cost: about $40 million total.
- With private/fleet buyers at $40,000/car, cost would be about $32 million from govmt.

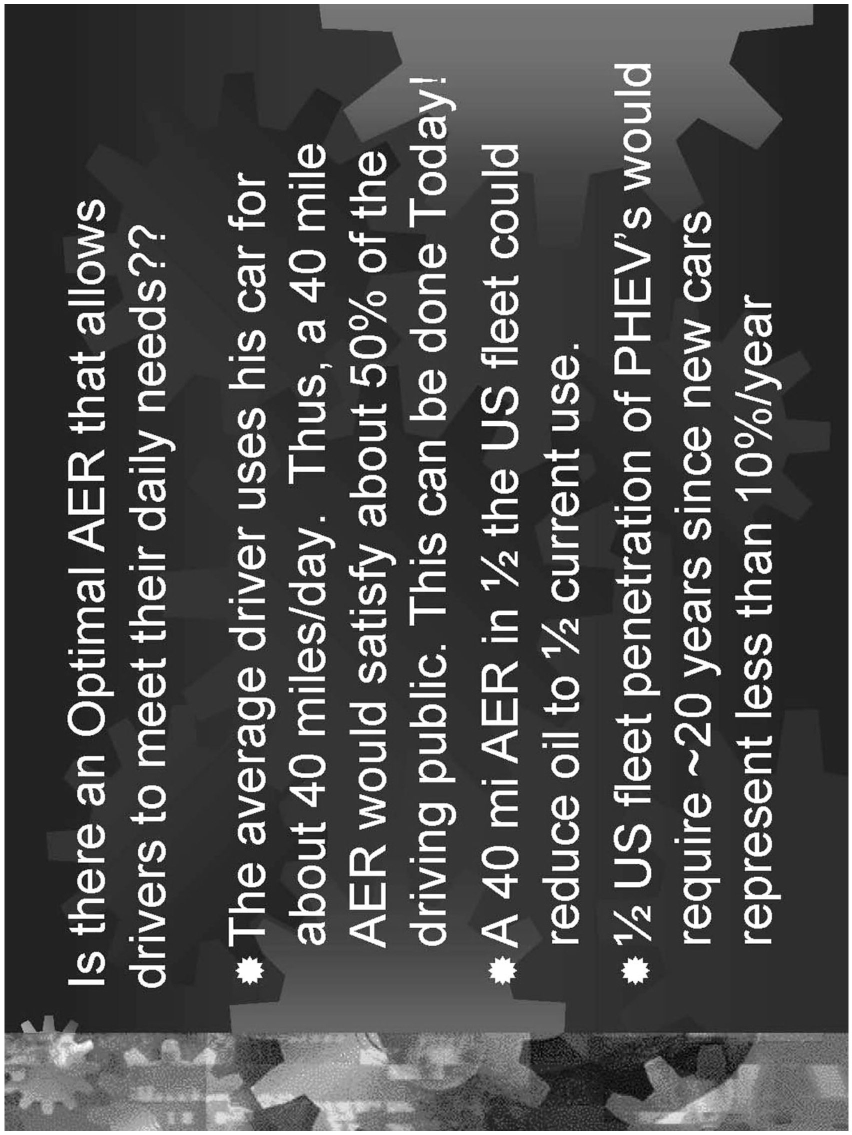
What are the technical and social BARRIERS to widespread adoption of PHEV's

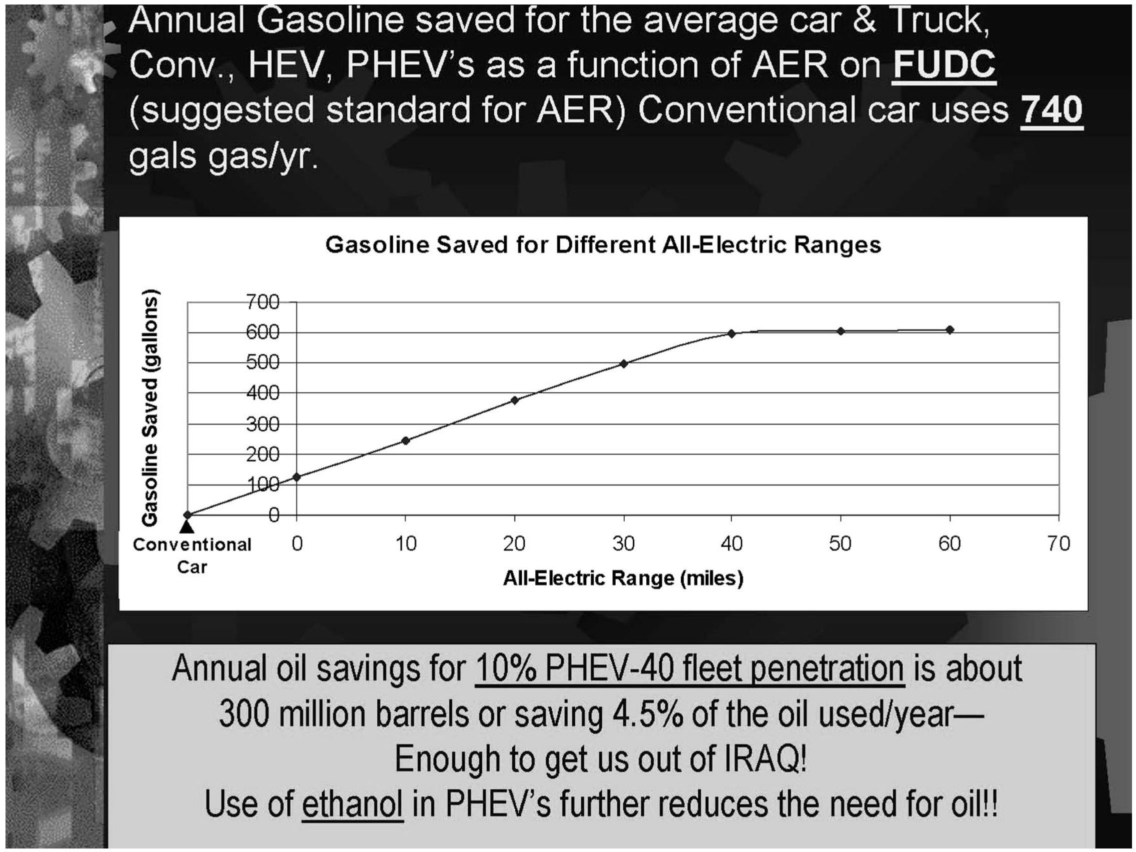
- Convincing the Auto and Oil companies that the PHEV is beneficial to their well being and will make them much more competitive today!
- Use of PHEV to integrate small Solar and Wind into Vehicle-Home-Office for new domestic Jobs and for an improved cleaner Society.
- Understanding PHEV's & reduced Vehicle fuel costs (15c/mi to less than 3c/mi)


Don't step back in technology
When we move forward to
sustainability!!!
Berliner Stadtgüter
Gut Birkholz
Werkstatt / MVA
TIERARZTPRAXIS

What are the technical and social BARRIERS to widespread adoption of PHEV's---Continued

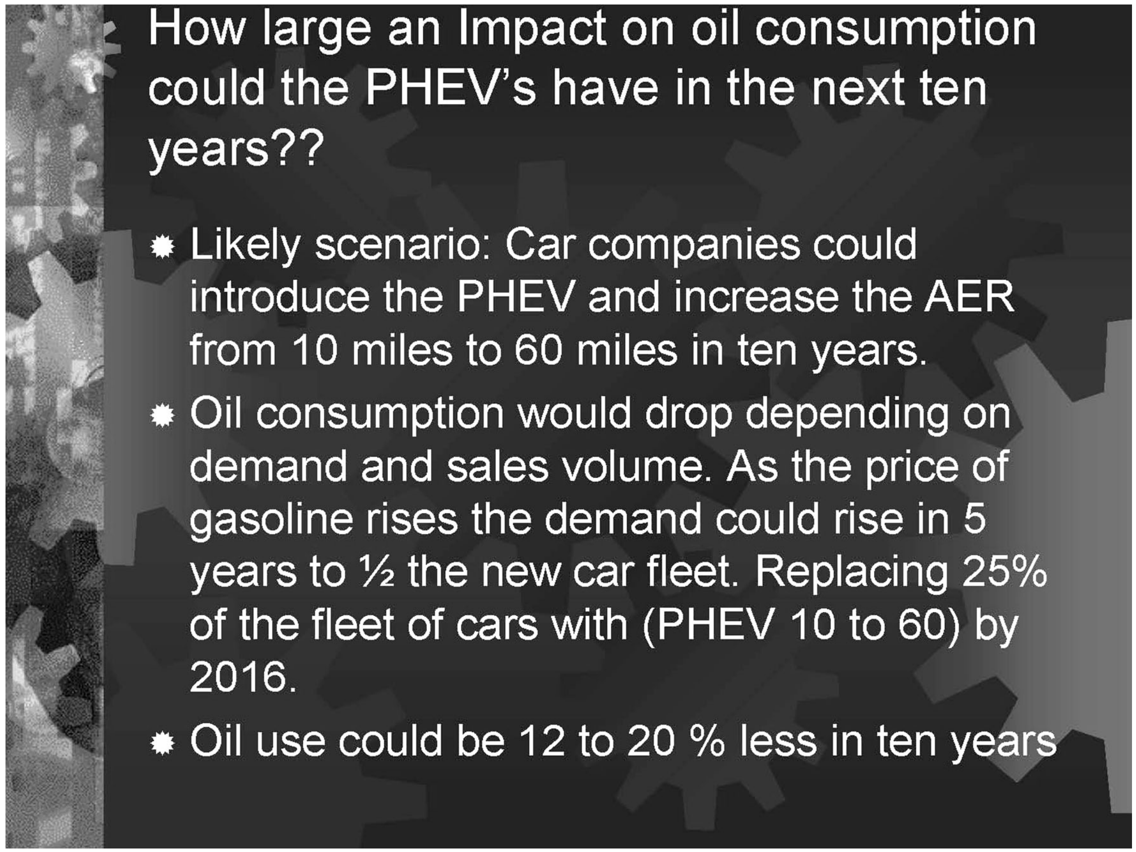
- The acceptance of home refueling and safety measures needed to insure safe operation of the house energy systems—Davis, CA--garage EV charger plug ordinance!
- The change of habits Plug –In your vehicle to save ¾ + of the fuel costs, reduce G.S. trips.
- The acceptance of high performance without noise or pollution
- The idea that we can move toward zero carbon society with NO lifestyle sacrifices


Is there an Optimal AER that allows drivers to meet their daily needs??
The average driver uses his car for about 40 miles/day. Thus, a 40 mile AER would satisfy about 50% of the driving public. This can be done Today!
A 40 mi AER in ½ the US fleet could reduce oil to ½ current use.
½ US fleet penetration of PHEV's would require ~20 years since new cars represent less than 10%/year

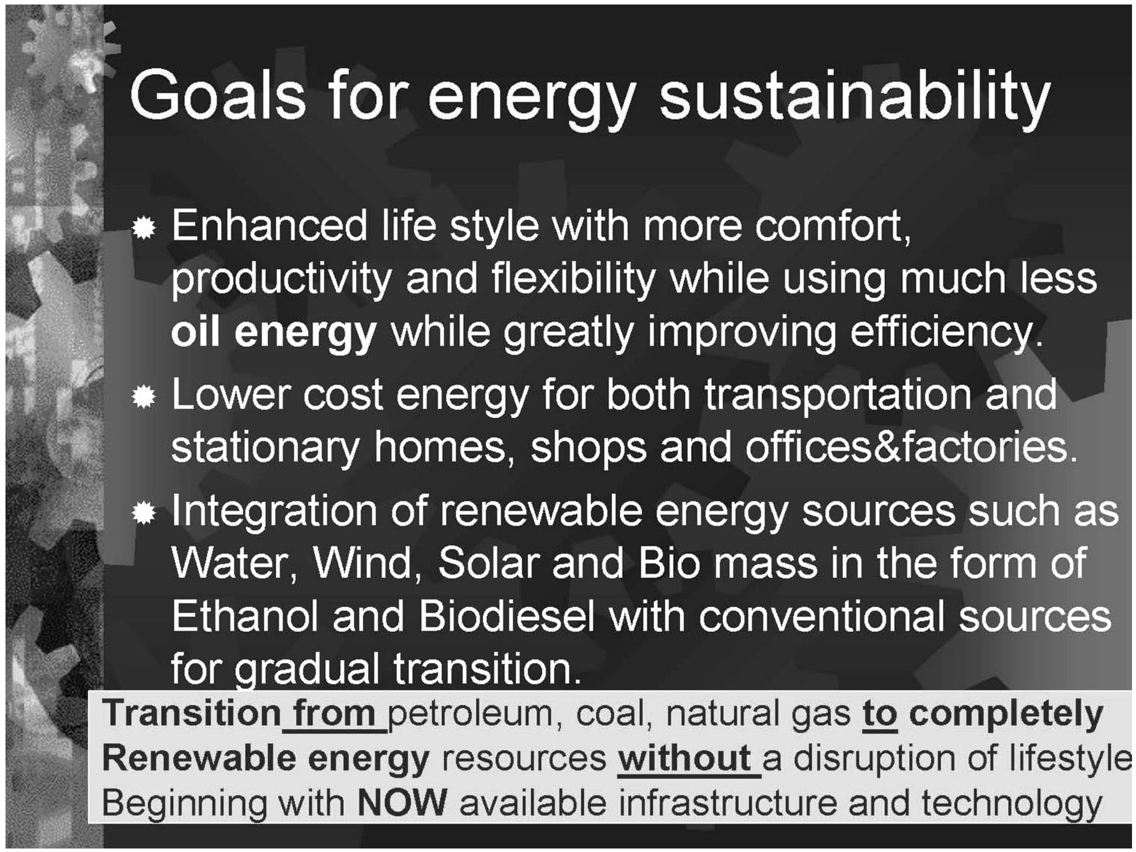

Annual Gasoline saved for the average car & Truck, Conv., HEV, PHEV's as a function of AER on **FUDC** (suggested standard for AER) Conventional car uses **740** gals gas/yr.
Gasoline Saved for Different All-Electric Ranges
Gasoline Saved (gallons)
700
600
500
400
300
200
100
0
Conventional Car
0
10
20
30
40
50
60
70
All-Electric Range (miles)
Annual oil savings for 10% PHEV-40 fleet penetration is about 300 million barrels or saving 4.5% of the oil used/year—
Enough to get us out of IRAQ!
Use of ethanol in PHEV's further reduces the need for oil!!

How long will it take before we see PHEV's in the marketplace?

- 2 year demonstrations and demand creation—government support needed!!
- One more year for production Launch
- 3 years total for volume production at about 50,000/year-with 2 OEM's
- 5 years- 500,000 to 1million /year by 3 to 5 OEM's across 3 platforms
- 10 years -7.5 million cars/year (½ the new car fleet). The PHEV introduction driver is liquid fuel costs


How large an Impact on oil consumption could the PHEV's have in the next ten years??
Likely scenario: Car companies could introduce the PHEV and increase the AER from 10 miles to 60 miles in ten years.
Oil consumption would drop depending on demand and sales volume. As the price of gasoline rises the demand could rise in 5 years to ½ the new car fleet. Replacing 25% of the fleet of cars with (PHEV 10 to 60) by 2016.
Oil use could be 12 to 20 % less in ten years

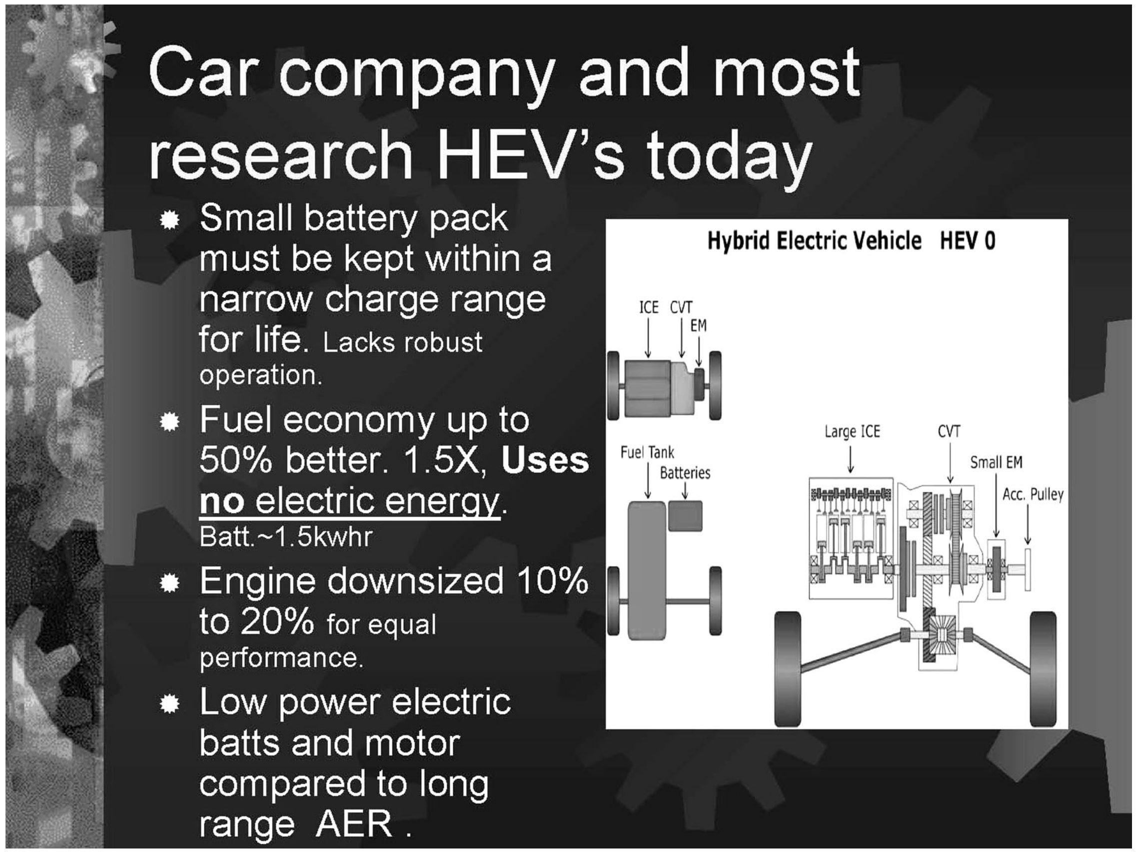

Appendix and supporting slides
Goals of sustainability
What is a PHEV
Definition of all electric range AER
Cost increment HEV
Potential sales volume vs costs
Petroleum reduction (EPRI)
CO2 emissions benefits (EPRI)



Goals for energy sustainability
Enhanced life style with more comfort, productivity and flexibility while using much less oil energy while greatly improving efficiency.
Lower cost energy for both transportation and stationary homes, shops and offices&factories.
Integration of renewable energy sources such as Water, Wind, Solar and Bio mass in the form of Ethanol and Biodiesel with conventional sources for gradual transition.
Transition from petroleum, coal, natural gas to completely Renewable energy resources without a disruption of lifestyle Beginning with NOW available infrastructure and technology

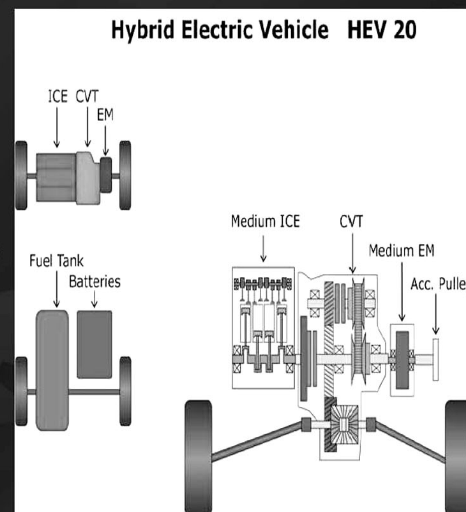
What is a Plug-In HEV??

- The Plug-In HEV is like a Toyota Prius except it has a **smaller** engine and a **larger** electric motor and **larger** battery pack and **a plug** to the wall to charge the batteries!!
- This combination allows the vehicle to have **better** fuel economy, **higher** performance, and All Electric Range **(AER)** up to 60 miles on the FUDC with a **much simpler** powertrain and no increase in weight. AER is done with batteries from 100% SOC to 20% SOC then the engine maintains at 20% SOC.
- Then when you stop driving you plug-in and fill the batteries from the wall with elect from powerplants or from renewable energy such as solar or wind If you don't plug-in you simply use more liquid fuel. Done with No change in performance!!


Car company and most research HEV's today
Small battery pack must be kept within a narrow charge range for life. Lacks robust operation.
Fuel economy up to 50% better. 1.5X, **Uses no** electric energy. Batt.~1.5kwhr
Engine downsized 10% to 20% for equal performance.
Low power electric batts and motor compared to long range AER .
Hybrid Electric Vehicle HEV 0
ICE
CVT
EM
Fuel Tank
Batteries
Large ICE
CVT
Small EM
Acc. Pulley

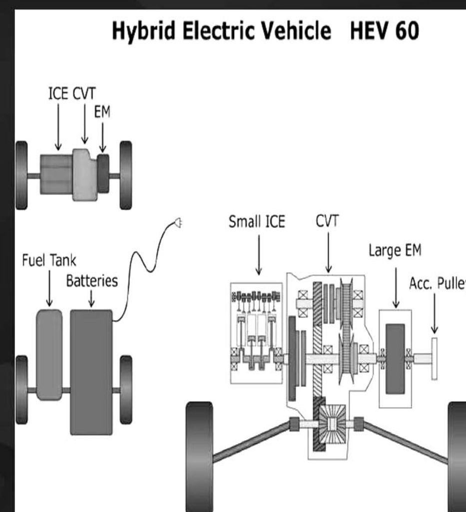
Medium range AER, 30 KM, HEV for lower Fuel use and emissions

- This size battery pack provides better fuel economy and all of the features of the HEV 0.
- Liquid fuel & electric grid energy use can be about 50/50. Batt.~9kwhr
- Engine about 2/3 CV.
- Battery life 120k km to 160k km (Mhd Ovonics).



Long range (100km)AER and Plug-In HEV and it's advantages

- 2X to 5X fuel/energy economy, 80% to 90% fewer mechanical parts. Weight equivalent to CV
- Uses Up to 90% wall elect. energy-10% liquid fuel annually.
- Higher performance than conventional vehicles possible.



Engine about 1/3 the CV and advanced <u>batteries lasting the life of the Car</u>. (Li or MHD)


ovonic solar
Shade and Charging Shelters
3.5 kW EV Charging Station
10 kW EV Charging Station
12 kW School Lunch Shelter
30 kW Parking Shade Structure

Cost effectiveness of Solar systems used to charge PHEV Batteries

- A 10 kw solar system charging PHEV's, is good for 30miles of driving for each hour of sun for a mid size car. (Cost-$8/watt-$3/watt rebate=$5/watt. New syst. cheaper)
- This is equivalent to producing a gallon of refined gasoline an hour ~ $3.00/hour.
- At $3.00/hour of operation and about 300 days a year at 8 hours of sun, the yearly money made by the 10kw array is about $7200.
- Payback should be about 6 years at this rate.

Solar is not so competitive with electricity at 4 cents/kwhr. Since it means that the revenue generated above would be only $0.40/hr Taking 48 years to pay back!!– A new industry is born!!


Wind mills that can use PHEV batteries to store generated energy rather than “waste it” or reducing power plant efficiency


Wind Turbine issues
When the wind blows, electricity generated must be used or wasted. Generating H2 has a lot of loss!!!
Wasting electricity by heat or throttling the wind mill is not cost effective because you are wasting a resource and not getting payback as quickly as you can. Feeding to the grid means throttling NG
Ideal for charging batteries of PHEV's can again displace gasoline use which is much more cost effective than trying to supplement electricity at 4 cents/kwhr. (Will go 3 to 4 times farther than H2) –means H2 "bar" is now 3 times higher!!
A 10 kw wind mill would be about 10 meters in diameter and could cost about $10,000. thus a payback time of about 3 to 4 years if used for charging PHEV cars. Another Industry!!

Additional uses for the large battery systems

- Batteries can be charged at night thus **balancing the electric grid** and raising the base load and reducing peak load generation with rolling reserves, thus reducing the cost of electricity to everyone!!
- Electric charging of the PHEV can be done at a **low power level, 1.5 to 2kw** , so there is no need for special charging stations. Standard 120 V GFI outlets will do. The standard Block

Gasoline reduction on an annual basis can be up to 80% to 90% . **Therefore;** The liquid fuel for these vehicles can easily be Ethanol/Bio-Diesel. Thus Reducing Petroleum Consumption to ZERO NOW!! Without having to go to H2!!


Where are these vehicle??
This is a **doable now** technology with no new technology breakthroughs needed for implementation. Only the Mind set of People!
The incremental cost over conventional cars can be less than 15% and today's components, suppliers are now available for most parts!
The car companies need to be convinced that people will buy if they build these vehicles
The price of gasoline will do it!! Since elect. at 6 cent/kwhr is equiv. to 70 cent/gal gasoline in a PHEV!!

Additional uses for the large battery systems

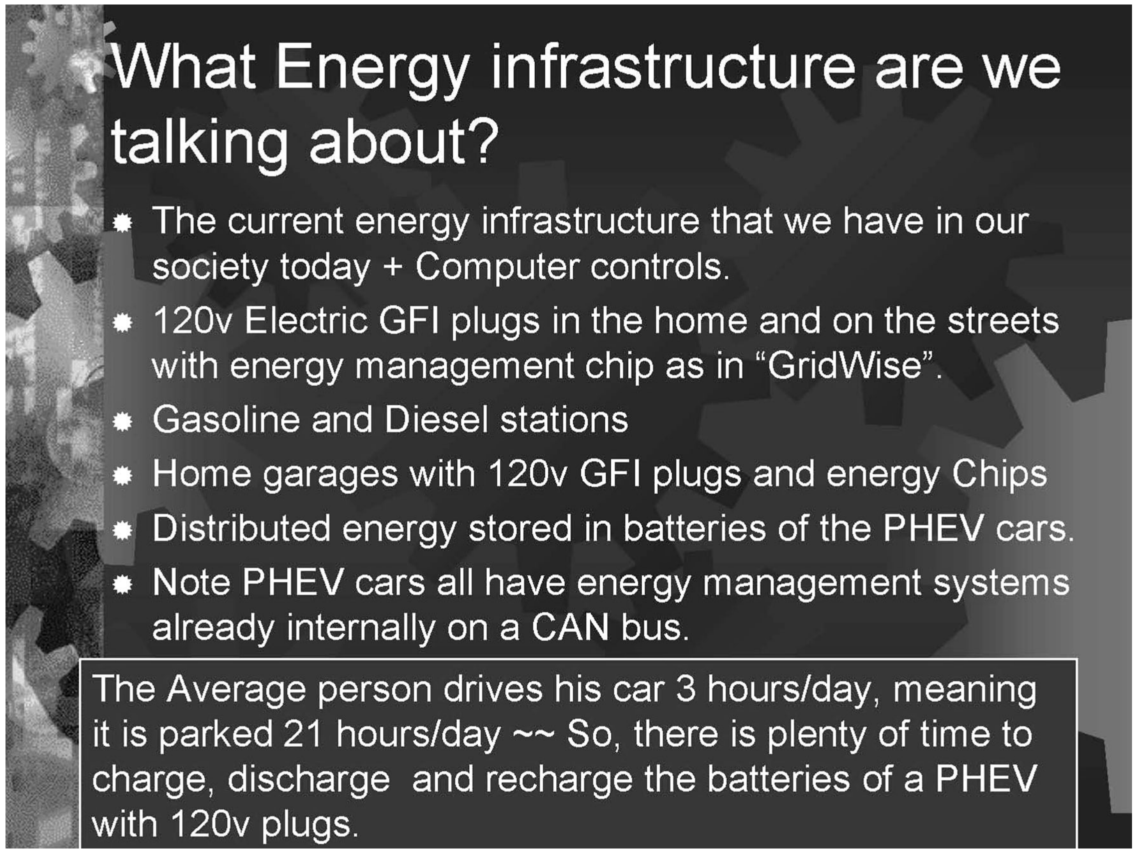
- Batteries can be charged at night thus **<u>balancing the electric grid</u>** and raising the base load and reducing peak load generation with rolling reserves, thus **reducing the cost** of electricity to everyone!!
- Electric charging of the PHEV can be done at a **low power level, 1.2 to 1.5kw** , so there is no need for special charging stations. Standard 120 V GFI outlets will do. The standard Block heater plugs in some towns will do just fine!

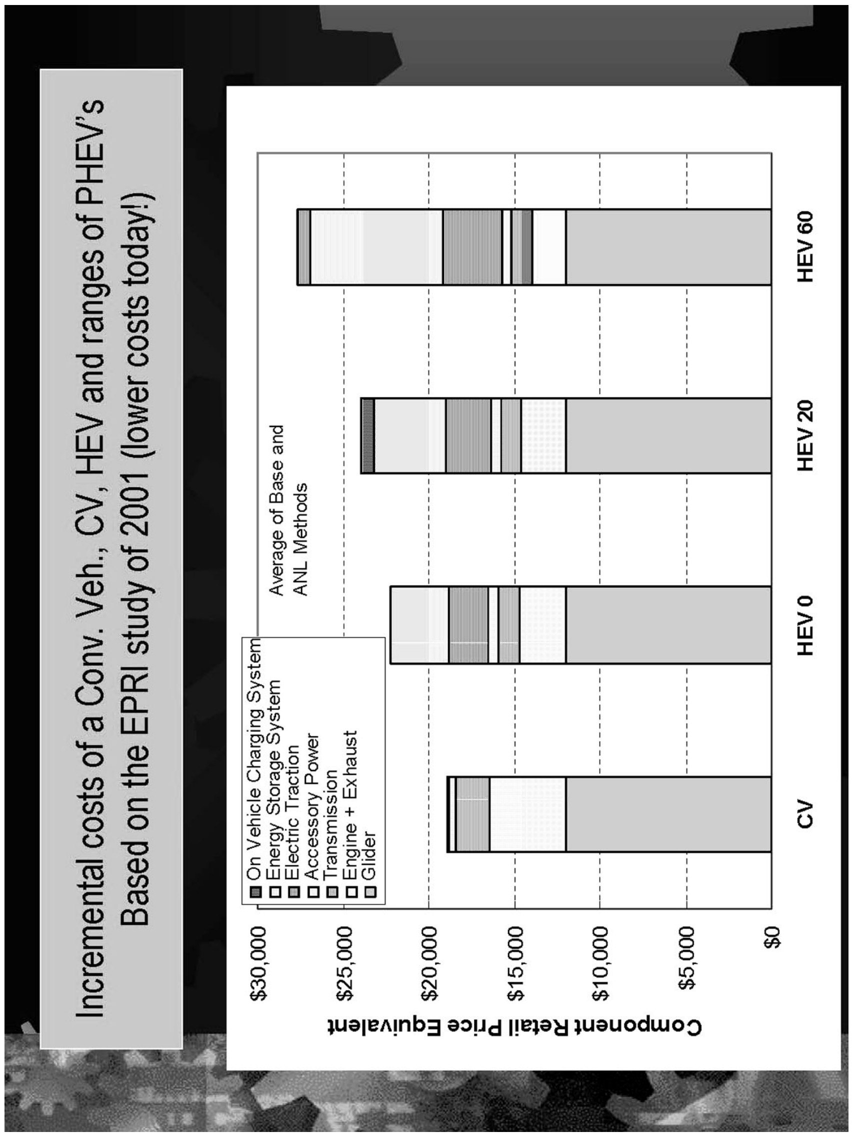
Car gasoline reduction on an annual basis can be up to 80% to 90% . **<u>Therefore;</u>** The liquid fuel for these vehicles can easily be Ethanol/Bio-Diesel. Thus Reducing <u>Petroleum Consumption to ZERO NOW!!</u> Without having to go to H2!!

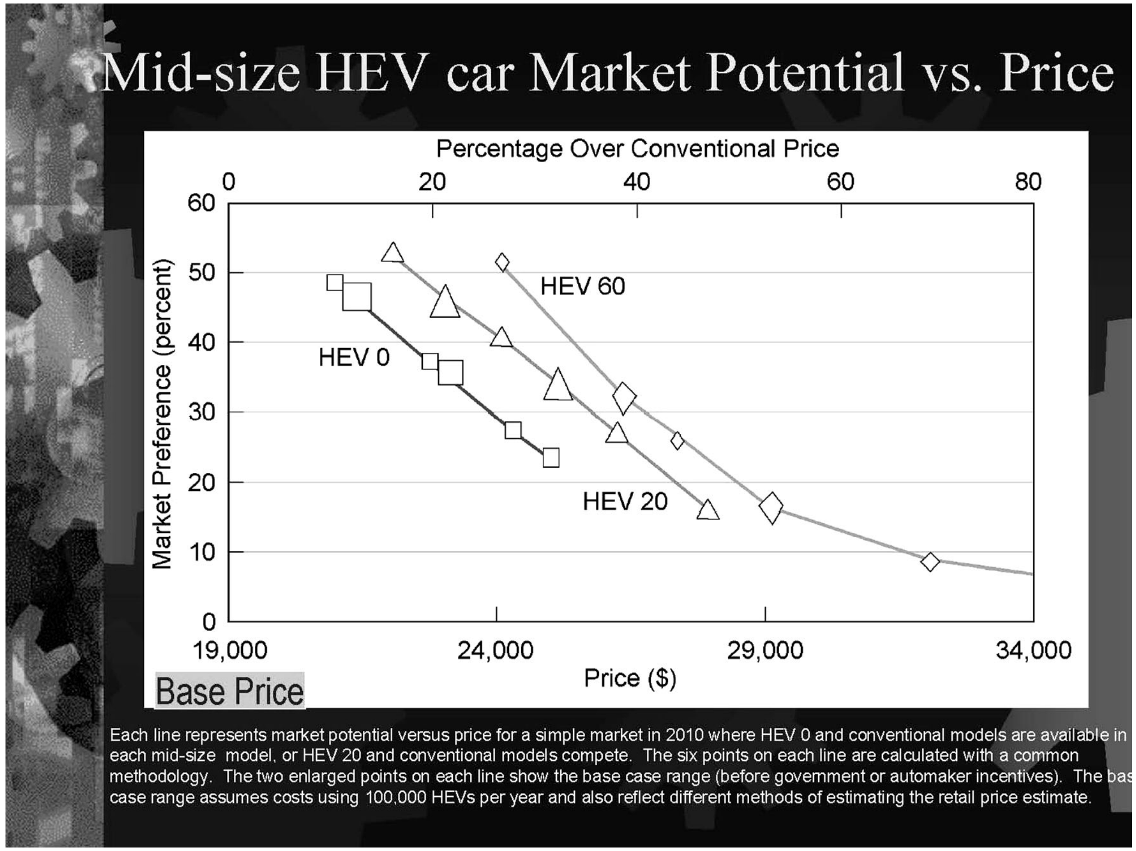
A Building Block for Sustainability using a Technology path with no change in Energy Infrastructure

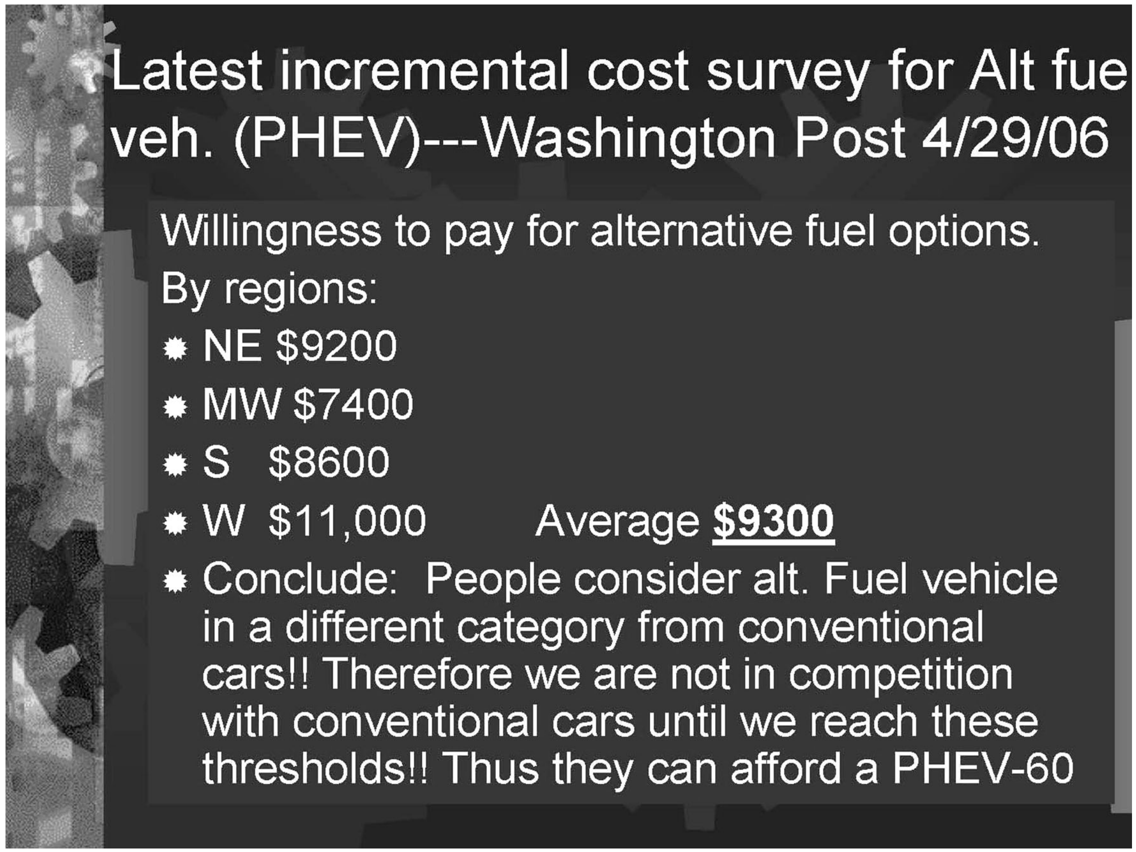
- The Plug-In Hybrid Electric Vehicle PHEV with enough batteries to provide 10 to 60 miles of all electric range **(AER).** From 5 to 30 kwhrs of batts- for SUV's.
- **Night time charging for batteries** from base electric plants and **daytime** charging with **solar**, **wind** or other **renewable** energies
- Night time use of vehicle battery energy for home electricity use including Cooking and Air Conditioning.

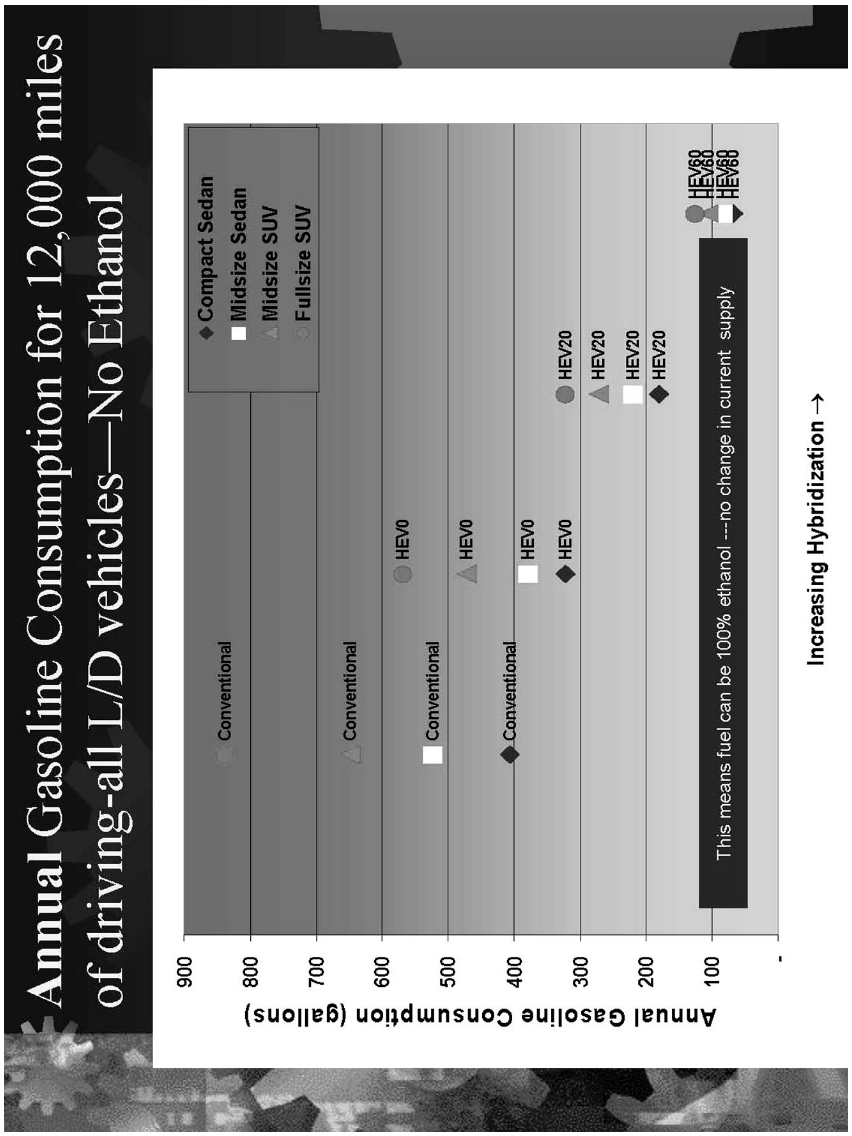
Daytime use of the PHEV batteries to reduce Daily Peak Electric needs, Spinning Reserves, and Voltage Regulation for The Electric Utilities, V2G

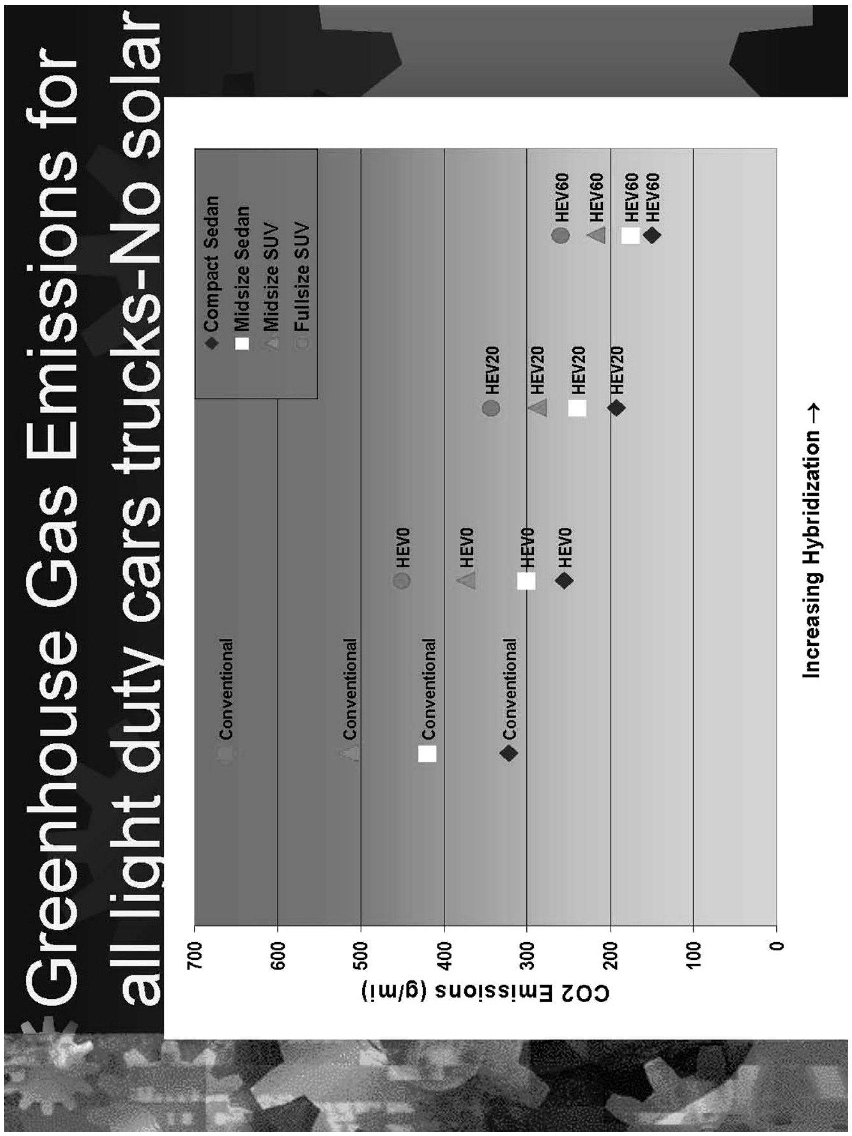

What Energy infrastructure are we talking about?
The current energy infrastructure that we have in our society today + Computer controls.
120v Electric GFI plugs in the home and on the streets with energy management chip as in "GridWise".
Gasoline and Diesel stations
Home garages with 120v GFI plugs and energy Chips
Distributed energy stored in batteries of the PHEV cars.
Note PHEV cars all have energy management systems already internally on a CAN bus.
The Average person drives his car 3 hours/day, meaning it is parked 21 hours/day ~~ So, there is plenty of time to charge, discharge and recharge the batteries of a PHEV with 120v plugs.

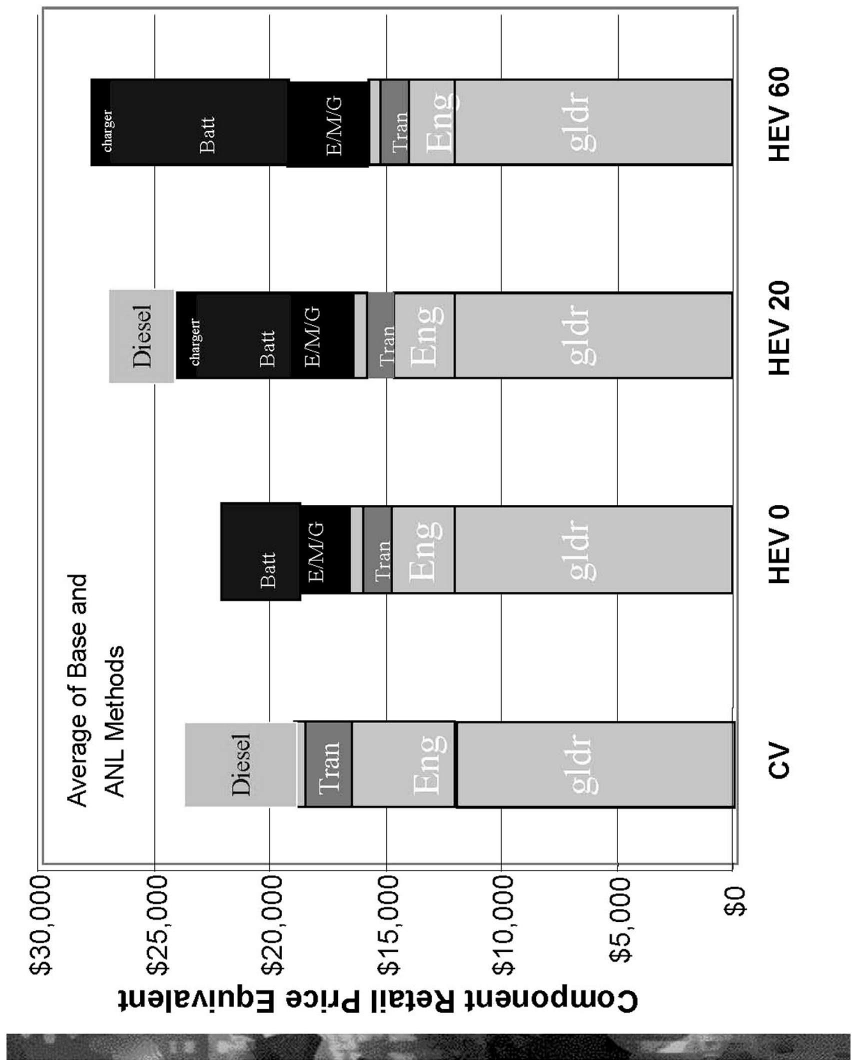

Incremental costs of a Conv. Veh., CV, HEV and ranges of PHEV's
Based on the EPRI study of 2001 (lower costs today!)
Component Retail Price Equivalent
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
On Vehicle Charging System
Energy Storage System
Electric Traction
Accessory Power
Transmission
Engine + Exhaust
Glider
Average of Base and
ANL Methods
CV
HEV 0
HEV 20
HEV 60


Mid-size HEV car Market Potential vs. Price
Percentage Over Conventional Price
0
20
40
60
80
Market Preference (percent)
0
10
20
30
40
50
60
HEV 0
HEV 20
HEV 60
19,000
24,000
29,000
34,000
Price ($)
Base Price
Each line represents market potential versus price for a simple market in 2010 where HEV 0 and conventional models are available in each mid-size model, or HEV 20 and conventional models compete. The six points on each line are calculated with a common methodology. The two enlarged points on each line show the base case range (before government or automaker incentives). The bas case range assumes costs using 100,000 HEVs per year and also reflect different methods of estimating the retail price estimate.


Latest incremental cost survey for Alt fue veh. (PHEV)---Washington Post 4/29/06
Willingness to pay for alternative fuel options.
By regions:
NE $9200
MW $7400
S $8600
W $11,000 Average $9300
Conclude: People consider alt. Fuel vehicle in a different category from conventional cars!! Therefore we are not in competition with conventional cars until we reach these thresholds!! Thus they can afford a PHEV-60


Annual Gasoline Consumption for 12,000 miles of driving-all L/D vehicles—No Ethanol
Annual Gasoline Consumption (gallons)
900
800
700
600
500
400
300
200
100
-
Compact Sedan
Midsize Sedan
Midsize SUV
Fullsize SUV
Conventional
Conventional
Conventional
Conventional
HEV0
HEV0
HEV0
HEV0
HEV20
HEV20
HEV20
HEV20
HEV60
HEV60
HEV60
HEV60
This means fuel can be 100% ethanol ---no change in current supply
Increasing Hybridization →

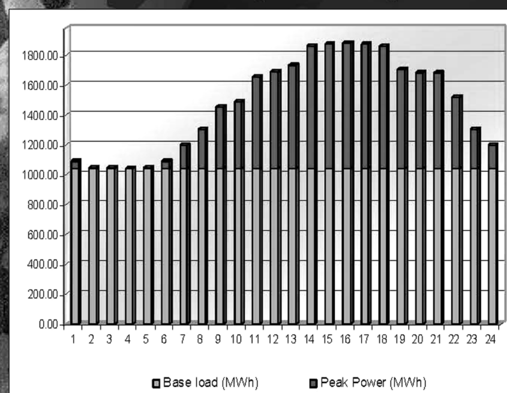

Greenhouse Gas Emissions for all light duty cars trucks-No solar
Compact Sedan
Midsize Sedan
Midsize SUV
Fullsize SUV
CO2 Emissions (g/mi)
700
600
500
400
300
200
100
0
Conventional
HEV0
HEV20
HEV60
Increasing Hybridization →

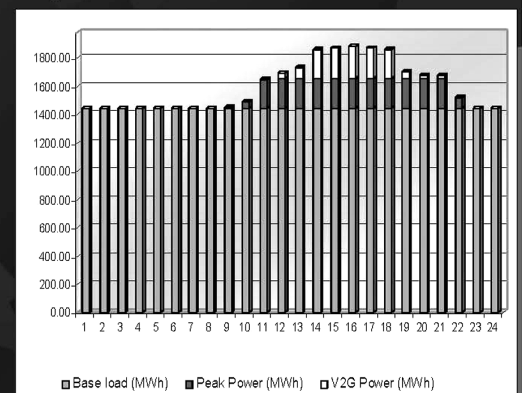


Component Retail Price Equivalent
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Average of Base and ANL Methods
CV
HEV 0
HEV 20
HEV 60
Diesel
Tran
Eng
gldr
Batt
E/M/G
chargerr
charger

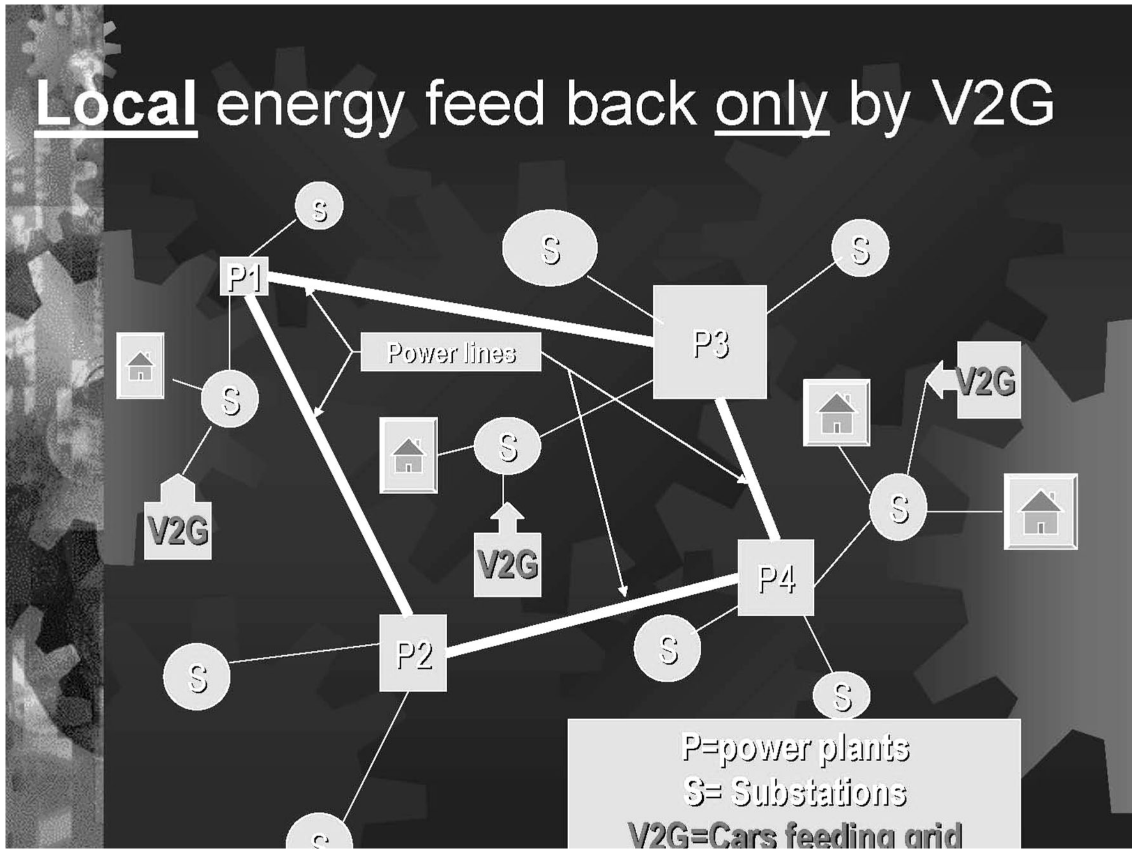
Grid-Integrating electric power and transportation energy sectors-20% penetration of the total car population-

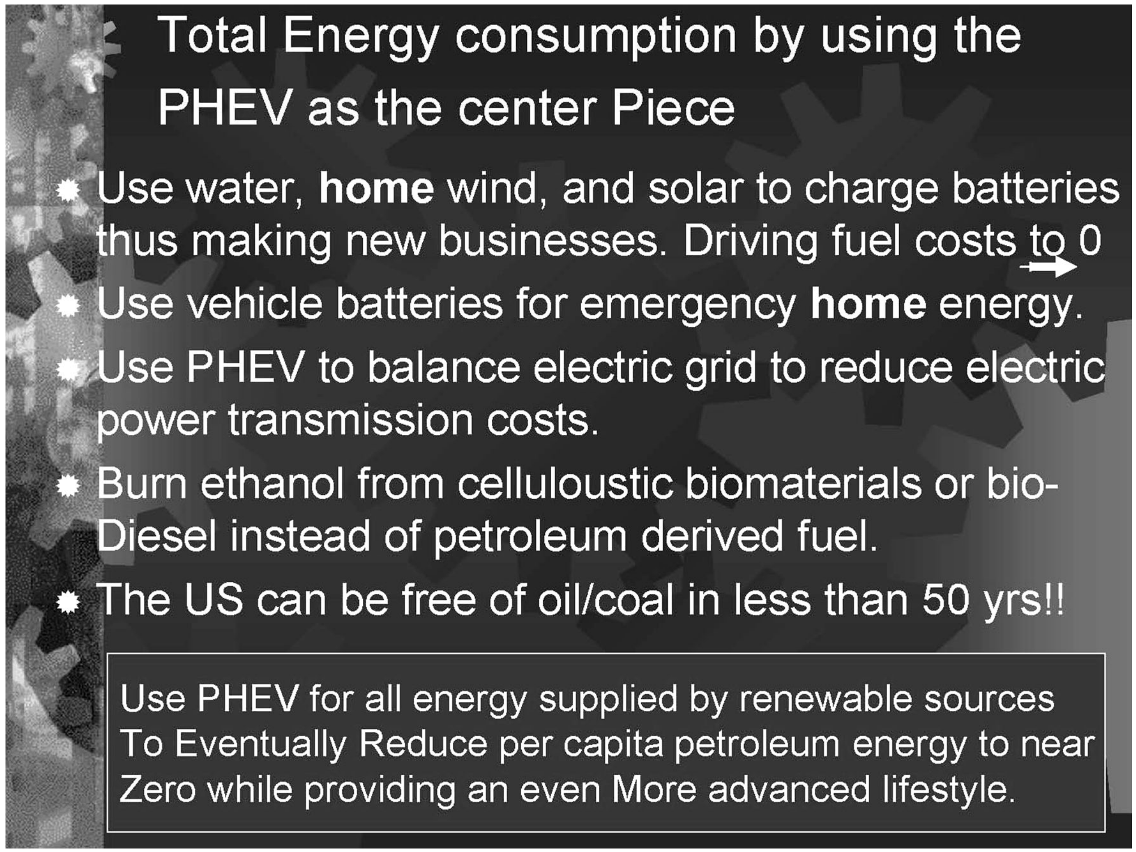
There's enough generating power for ½ Fleet with no more power plants!! --20 years at least!!





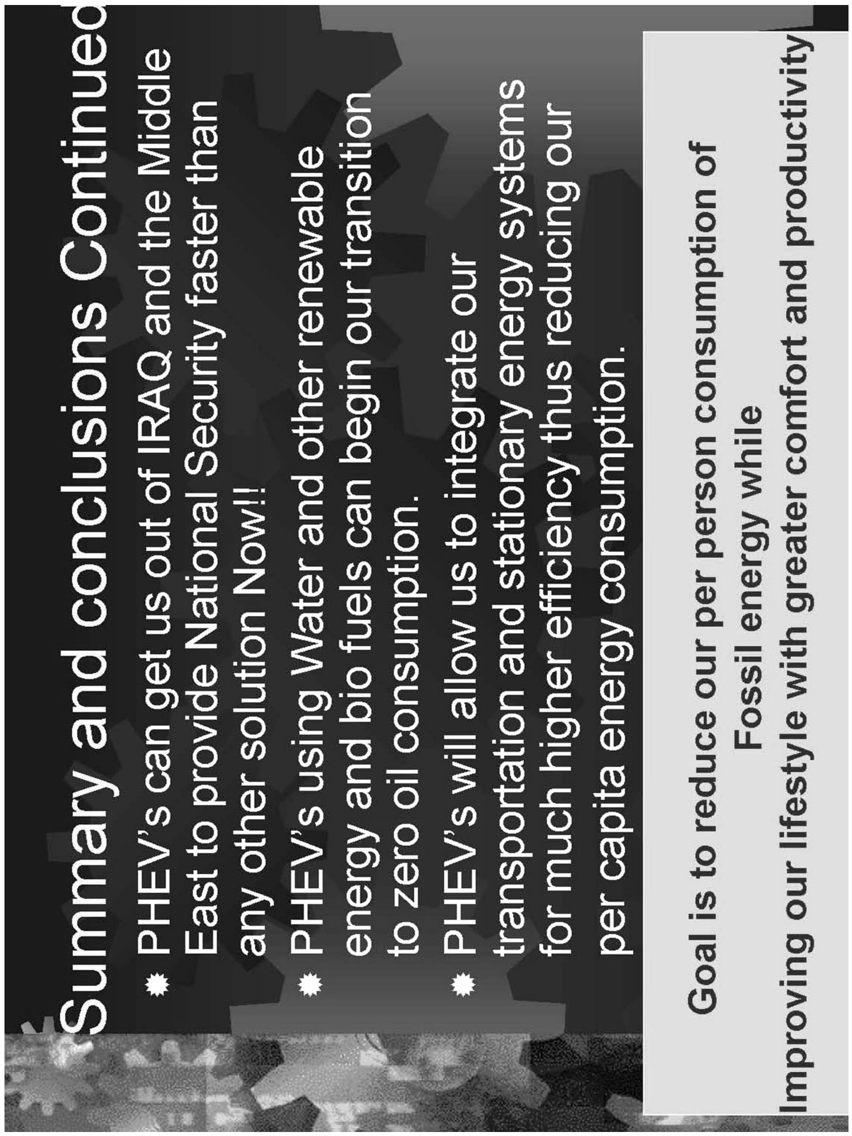
Energy available for the grid (V2G)	0	Mwh	Consumption without V2G	35300	Mwh	Total Base load before	24960	Mwh	Total Peak Power before	10340	Mwh
[redacted]e for recharging vehicles	4	Mwh	Consumption with V2G	37068	Mwh	Total Base load after	34560	Mwh	Total Peak Power after	2508	Mwh
Nb of vehicles	125000	#	Consumption increase	5.01	%	Base load increase	38.46	%	Peak Power decrease	75.74	%

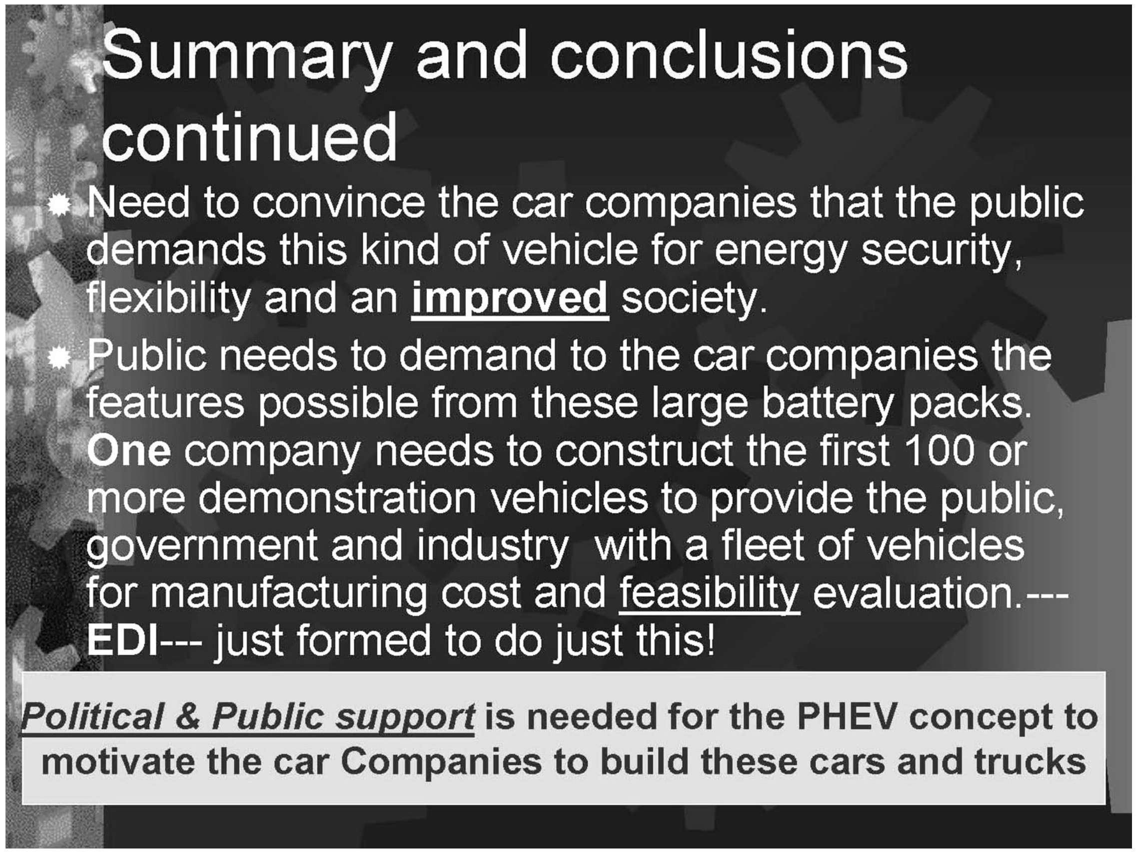

Local energy feed back only by V2G
S
S
S
P1
P3
Power lines
S
S
V2G
V2G
S
V2G
P4
S
P2
S
S
P=power plants
S= Substations
V2G=Cars feeding grid


Total Energy consumption by using the PHEV as the center Piece
Use water, **home** wind, and solar to charge batteries thus making new businesses. Driving fuel costs to 0
Use vehicle batteries for emergency **home** energy.
Use PHEV to balance electric grid to reduce electric power transmission costs.
Burn ethanol from celluloustic biomaterials or bio-Diesel instead of petroleum derived fuel.
The US can be free of oil/coal in less than 50 yrs!!
Use PHEV for all energy supplied by renewable sources To Eventually Reduce per capita petroleum energy to near Zero while providing an even More advanced lifestyle.

Summary and Conclusions

- PHEV's are a low cost solution to environmental & Energy Security problems and could provide high profits and employment for early investors.
- These vehicles can be brought to production now with little investment in development. No change in manufacturing and fuel infrastructure is needed!!
- PHEV's can begin the integration of Society's Energy systems to move toward an all electric society by reducing petroleum consumption by 50% to 100%.
- Can be an interim solution for the next 50 years to move society toward development of new vehicle and energy concepts such as H2 Fuel Cells or whatever???? But "Bar" is 3X higher!!


Summary and conclusions Continued
PHEV's can get us out of IRAQ and the Middle East to provide National Security faster than any other solution Now!!
PHEV's using Water and other renewable energy and bio fuels can begin our transition to zero oil consumption.
PHEV's will allow us to integrate our transportation and stationary energy systems for much higher efficiency thus reducing our per capita energy consumption.
Goal is to reduce our per person consumption of Fossil energy while
Improving our lifestyle with greater comfort and productivity


Summary and conclusions continued
Need to convince the car companies that the public demands this kind of vehicle for energy security, flexibility and an improved society.
Public needs to demand to the car companies the features possible from these large battery packs. One company needs to construct the first 100 or more demonstration vehicles to provide the public, government and industry with a fleet of vehicles for manufacturing cost and feasibility evaluation.--- EDI--- just formed to do just this!
Political & Public support is needed for the PHEV concept to motivate the car Companies to build these cars and trucks

BIOGRAPHY FOR ANDREW A. FRANK

Professor Frank received a Ph.D. in Electrical Engineering in 1967 from the University of Southern California, he has a Master's and Bachelor's degree in Mechanical Engineering, 1955 and 1957 from UC–Berkeley. He worked in the aerospace industry for over ten years on such projects as the Minute Man Missile, and the Apollo space craft to the Moon. He holds patents on helicopter stability systems from this period.

After his Ph.D. from USC in 1967, he became a Professor at the University of Wisconsin. While there, his research turned toward advance transportation systems for much higher fuel efficiency. A goal of developing cars with 100 mpg and 0 to 60 mph in six seconds or less was set then. He began research on the hybrid electric drive train to improve fuel efficiency. He received nine patents in the next 18 years on various flywheel and electric drive systems for automobiles. He left Wisconsin for his present position at the University of California–Davis in 1985.

Since coming to UC–Davis, he has continued research into super fuel efficiency. In 1992 he and his student team set the world record in super fuel efficiency by constructing a car with his students that achieved 3300 mpg on gasoline and another car at 2200 mpg on M–85. These vehicles set the boundary of what is possible but are not real practical cars since they weigh less than 100 lbs.

Since then he and his students have been designing and constructing plug-in hybrid electric vehicles which have the capability of using electric energy from the utility system and ordinary gasoline. All this research is being done in the U.S. DOE GATE Center for Hybrid Electric Vehicle Research. Recent studies from the Center show that such cars will reduce gasoline consumption by 75 percent or more, and provide two times the energy efficiency while providing zero emission driving capability with no change in the energy infrastructure. As part of this research program a large amount of effort is also being spent on Continuously Variable Transmission design development and theory. The research in the CVT allows vehicles to be either a conventional vehicle or a hybrid with no change in the power train. The CVT systems designed by Dr. Frank and associates have no power or torque limitations and are over 95 percent efficient. At the Center, we have developed world class research in these areas.

Professor Frank is the author of over 120 publications and currently holds 27 patents with many more pending.

Professor Frank has worked as a consultant on patent problems, electrical accidents, and design defect cases for the last 30 years.

Chairwoman BIGGERT. Thank you, Dr. Frank.

Mr. Duncan, you are recognized.

STATEMENT OF MR. ROGER DUNCAN, DEPUTY GENERAL MANAGER, AUSTIN ENERGY IN TEXAS

Mr. DUNCAN. Madame Chairman and Members of Congress, thank you for inviting me today to give testimony on the proposed legislation regarding plug-in hybrid vehicles. We have several expert witnesses today to speak to the technical aspects of how a flexible fuel plug-in hybrid vehicle works, and the state of research and development of such a vehicle.

In my opinion, any obstacles in research and development will be met by the proposed legislation. I believe that the battery issues can be rather easily addressed, and I do not think that there are any major infrastructure issues to overcome, because the infrastructure is the existing electric grid.

The main obstacle I see to widespread commercial application of these vehicles is automotive industry inertia based on a perception that there is not a commercially viable market. So today, I will focus on customer acceptance and the potential market for these vehicles, specifically the Plug-In Partners campaign currently being conducted by the City of Austin.

We became very excited in Austin when we found out about plug-in hybrid electric vehicles. These vehicles can reduce America's reliance on foreign oil, decrease greenhouse gas emissions from automobiles, and help Americans save on fuel costs.

In Austin, citizens could charge their vehicles overnight and then drive around town the next day on the electric equivalent of 75-cents-a-gallon gasoline. The equivalent cost of electricity in our nation anywhere is under a dollar a gallon. And we were also very excited in Austin when we realized that we could use our Green Choice renewable energy program, which is primarily wind-based, as a transportation fuel.

Our Mayor, Will Wynn, now proudly tells people that in Austin we intend to replace Middle Eastern oil with West Texas wind. And the fueling infrastructure is already in place. In fact, we have an alternative vehicle fueling station in this hearing room today: the electric wall socket.

Last August, our city, county, chamber of commerce, and local environmentalists joined together to kickoff the Plug In Austin campaign. Our utility is setting aside $1 million in rebates for the first plug-in hybrids in our service area. And we came up with the idea of "soft" fleet orders, asking our partners to seriously consider purchasing such vehicles if they became available.

We realized, however, that the automakers were not going to make these vehicles just for Austin, Texas, even though we are the home of the national champion Texas Longhorns.

So my Mayor and Council said to take this campaign to the 50 largest cities in the Nation, and we launched the Plug-In Partners campaign here in Washington four months ago.

Today, we are proud to be joined in this effort by cities such as Los Angeles, Chicago, Phoenix, Philadelphia, Baltimore, Dallas, Fort Worth, Memphis, Denver, Salt Lake City, Kansas City, San Francisco, Seattle, Boston, and many other cities and counties.

Since we are promoting a flexible-fuel plug-in hybrid, the American Corn Growers Association and the Soybean Producers of America have joined us.

Our broad-based coalition now has over 200 partners throughout state and local governments, non-profit organizations, including environmental and national security organizations, public and private utilities, and businesses.

We already have "soft" fleet orders for over 5,000 vehicles.

But almost all of our partners ask me the same question: where can I get one? The proposed legislation will be very helpful in this regard. The demonstration program in this legislation will directly address our most pressing need, providing demonstration vehicles to the state and local governments, businesses, and other Plug-In Partners. We will help in matching the great consumer demand that we are uncovering with the demonstration program proposed in this legislation.

The only additional recommendation I have is to consider federal fleet commitments. The diversity of federal vehicles would provide a wonderful testing and demonstration platform for this new technology. We would also ask you to encourage the Postal Service to transition their neighborhood delivery vehicles to plug-in hybrids and to perhaps provide incentives to the post office for that transition. This type of vehicle is perfect for this technology, and it would show everyone in the country what they are.

In conclusion, we believe the proposed legislation is a very important step in addressing the energy crisis facing this nation and encourage you to move forward with it.

Thank you.

[The prepared statement of Mr. Duncan follows:]

PREPARED STATEMENT OF ROGER DUNCAN

Madame Chairman and Members of Congress, thank you for inviting me today to give testimony on the proposed legislation regarding plug-in hybrid vehicles. Solving the energy crises that America faces today requires new and innovative thinking and I am glad to see that this committee has focused on what I consider to be one of the prime solutions.

You have several expert witnesses today to speak to the technical aspects of how a flexible fuel plug-in hybrid vehicle works and the state of research and development of such a vehicle. In my opinion, any obstacles in research and development will be met by the proposed legislation. I believe that the battery issues can be easily addressed and I do not think there are any major infrastructure issues to overcome—because the infrastructure is the existing electric grid.

The main obstacle I see to widespread commercial application of these vehicles is automotive industry inertia based on a perception that there is not a commercially viable market. So today I will focus on customer acceptance and the potential market for these vehicles—specifically the Plug-In Partners campaign currently being conducted by the City of Austin.

We became very excited in Austin when we found out about plug-in hybrid electric vehicles. These vehicles can reduce America's reliance on foreign oil, decrease greenhouse gas emissions from automobiles, and help Americans save on fuel costs.

Also, plug-in hybrid vehicles can also be built with flexible fuel engines, magnifying the national security, environmental and economic benefits while also increasing business for American agriculture.

In Austin we are particularly interested in electricity because if an Austin citizen could charge their vehicle overnight, they could drive around town the next day on the electric equivalent of 75 cents a gallon gasoline. As we checked utility rates around the country, we realized that the equivalent cost of electricity anywhere in our nation is under a dollar a gallon. And we were also very excited in Austin when we realized that we could use our Green Choice renewable energy program, which is primarily wind-based, as a transportation fuel.

Our Mayor, Will Wynn, now proudly tells people that in Austin we intend to substitute West Texas wind for Middle Eastern oil. And the fueling infrastructure is already in place. In fact, we have an alternative vehicle fueling station in this hearing room today, the ordinary electric wall socket.

Our Mayor and Council launched Plug-in Austin last August. The city, county, chamber of commerce, and local environmentalists joined together to kick off the campaign. Austin Energy, the City of Austin's public utility, is setting aside a million dollars in rebates for the first plug-in hybrids in our service area. And we came up with the idea of "soft" fleet orders, asking our partners to seriously consider purchasing such vehicles if they became available.

We realized, however, that the automakers were not going to make these vehicles just for Austin, Texas—even though we are the home of the national champion Texas Longhorns.

So out Mayor and Council said to take this campaign to the 50 largest cities in the Nation and we launched the Plug-In Partners campaign here in Washington four months ago.

Today we are proud to have been joined in this effort by cities such as Chicago, Los Angeles, Phoenix, Philadelphia, Dallas, Fort Worth, Memphis, Denver, Salt Lake City, Kansas City, San Francisco, Seattle, Boston, and many other cities and counties.

Since we are promoting a flexible-fuel plug-in hybrid, the American Corn Growers Association and the Soybean Producers of America have joined the coalition.

Our broad based coalition now has over 200 partners throughout State and local governments, non-profit organizations—including environmental and national security organizations, public and private utilities, and businesses. We already have "soft" fleet orders for over 5,000 vehicles. A complete list of our partners had been provided.

But almost all our partners ask me the same question—where can I get one? And this is one place where I think the proposed legislation will be very helpful. The demonstration program proposed in the legislation will directly address our most pressing need—providing demonstration vehicles to the State and local governments, businesses and other Plug-In Partners. We will help in matching the great consumer demand that we are uncovering with the demonstration program proposed in this legislation.

If I were to recommend that anything at all be added to the legislation, it would be consideration of federal fleet commitments. The diversity of federal vehicles would provide a wonderful testing and demonstration platform for this new technology. We would also ask you to encourage the Postal Service to transition their neighborhood delivery vehicles to plug-in hybrids and to perhaps provide incentives to the Post Office for that transition. These types of vehicles are perfect for this technology, and it would show everyone in the country what they are.

In conclusion, we believe the proposed legislation is a very important step in addressing the energy crises facing this nation and encourage you to move forward with it. Thank you.

BIOGRAPHY FOR ROGER DUNCAN

Roger Duncan is the Deputy General Manager of Austin Energy, the Municipal Utility for Austin, Texas. He manages Strategic Planning, Government Relations, On-site Generation, Demand-side Management, and Green Building for the Utility. Prior to joining Austin Energy, Mr. Duncan was Director of the Environmental Department for the City of Austin and was elected to two terms on the Austin City Council.

Mr. Duncan is currently Co-chair of the Urban Consortium Sustainability Council and serves on the Board of Directors of the Environmental and Energy Study Institute and the Electric Drive Transportation Association. He also is a member of the Western Governor's Association Committee on Energy Efficiency and was appointed by the Secretary of Energy to the Federal Energy Management Advisory Council.

Mr. Duncan holds a B.A. degree with a major in Philosophy, University of Texas at Austin.

Chairwoman BIGGERT. Thank you, Mr. Duncan.

I have to say that you did forget one city when you were mentioning all of those, and that is Naperville, Illinois, which is the largest city in my suburban Chicago district, but they are a Plug-In Partner and one of the campaign's founding members. I am not sure if the campaign has switched to—from cities to individuals yet, but if it has, that makes the list. I would buy a plug-in hybrid if they were available today.

Thank you.

Dr. Duvall, you are recognized for five minutes.

STATEMENT OF DR. MARK S. DUVALL, TECHNOLOGY DEVELOPMENT MANAGER, ELECTRIC TRANSPORTATION & SPECIALTY VEHICLES, SCIENCE & TECHNOLOGY DIVISION, ELECTRIC POWER RESEARCH INSTITUTE (EPRI)

Dr. DUVALL. Thank you, Chairman Biggert, for the opportunity to address your committee.

I would like to briefly highlight a few key points of the written testimony I have submitted in response to questions posed by the Committee, and I look forward to any additional inquiries you have.

In 2000, EPRI created a Hybrid Electric Vehicle Working Group. It was a collaboration with Ford, General Motors, several of our utility members, some state and local agencies, and two National Laboratories, Argonne National Lab, and the National Renewable Energy Laboratory, and others. This group of stakeholders completed the first comprehensive study on the benefits, costs, technical challenges, and market potential of conventional hybrid and plug-in hybrid electric vehicles.

EPRI used this study as a roadmap to guide research and development activities over the past six years on battery technology, control system development, infrastructure, and also on environmental analysis. While the R&D continues, EPRI has worked with others to inform federal and State policy-makers about the energy security benefits of plug-in hybrids, reducing U.S. dependency on petroleum while maintaining the usefulness and utility of conventional automobiles.

During this work, we found that the cost and durability and safety of advanced battery technologies were high-priority development issues, followed closely by other overall electric drive system development and integration issues. Our current experience suggests that these technologies are sufficiently well developed to move plug-in hybrid technology to the market for early entry. It further suggests that continuing R&D on key component technologies is critical and has the potential to significantly improve the performance of the technology, especially with respect to advanced batteries.

I would like to highlight three important actions that can dramatically improve near-term prospects for plug-in hybrid vehicles, and which I believe are also supported well by the draft legislation.

The first is to establish programs with automotive manufacturers to develop production prototype plug-in hybrid vehicles and to demonstrate them with private and public fleets. One example of this type of program is a collaboration between EPRI and DaimlerChrysler with several electric utilities and the South Coast Air Quality Management District in southern California to test a fleet of plug-in hybrid delivery vans with advanced battery technology. These prototypes are currently undergoing extensive testing in Germany and Los Angeles and currently demonstrating excellent performance with the potential to provide long-term durability in a demanding application.

The second is to develop a plan for acquiring and deploying larger fleets of plug-in hybrid vehicles in various vehicle platforms and configurations for multiple locations across the United States. Plug-in hybrid vehicles have a wide variety of application to different platforms. We should not assume that they are only for small passenger cars. They can serve many different needs. One example is that EPRI and some of the utilities are working with a major hybrid drive system manufacturer to develop a plug-in hybrid electric utility vehicle that can go and repair distribution lines in neighborhoods using only electricity, without exposing the operator to harmful diesel emissions, and while providing backup power to customers during some outages.

There are always additional costs and risks associated with the development of new technology, and large scale fleet demonstrations help to minimize these issues and build market familiarity with plug-in hybrids and create a minimum level of certainty for the first-to-market manufacturers.

Finally, the creation of national research programs focused on increasing the overall performance of batteries, electric drive systems, and power electronics. The Department of Energy recently held a meeting to define key plug-in hybrid research challenges, and this effort should be fully supported as much and as soon as possible.

One of the most important benefits of plug-in hybrid vehicles is the ability to diversify our transportation energy sources by displacing a portion of the sector's petroleum consumption with electricity. At high levels of market penetration, PHEVs can achieve dramatic reductions in petroleum consumption with a modest increase in the nationwide electricity demand. The electric sector has a large capacity to provide for electricity for transportation uses with minimal adverse impact and several significant potential benefits to the electric grid as a whole.

The effort to move PHEVs into commercialization must be a serious one, given the current status of the technologies. And this is an achievable near-term objective with enormous potential to reduce national petroleum consumption, to lower transportation fuel costs, to diversify and secure transportation energy sources, and to reduce vehicle emissions.

In closing, I would like to thank Chairman Biggert and the Members of Congress for your attention, and I look forward to your questions.

[The prepared statement of Dr. Duvall follows:]

PREPARED STATEMENT OF MARK S. DUVALL

On behalf of the Electric Power Research Institute, I appreciate the opportunity to address your committee. My remarks will offer a brief history of plug-in hybrid electric vehicle development, the current status of the technology and answers to some questions posed by Committee staff.

Recent History of Plug-in Hybrid Electric Vehicle Development

In 2000, EPRI created a Hybrid Electric Vehicle Working Group (HEVWG) in conjunction with Ford, General Motors, Argonne National Laboratory, National Renewable Energy Laboratory, New York Power Authority, Southern Company and Southern California Edison. The HEVWG was supported by a consulting team with a strong background in marketing, emissions, and cost analysis.

The resulting study that compared the benefits, costs and challenges between conventional vehicles, hybrid vehicles and plug-in hybrid vehicles (PHEV) set the stage for additional research over the past six years on battery technology, control system development, infrastructure, and environmental analysis. While R&D continues, EPRI has worked with other advocates to inform federal and State policy-makers about the energy security benefits of plug-in hybrids—reducing U.S. dependency on petroleum while maintaining the usefulness and utility of conventional automobiles.

This R&D work identified the challenges facing plug-in hybrid commercialization. We found that the cost and durability of advanced battery technologies was the highest priority, followed closely by battery system and drive system vehicle integration and coordinated energy management. The analysis to date suggests that the technology, control systems and advanced battery systems are sufficient to move plug-in hybrid technology to the market at an early entry level. It further suggests that continued R&D on key component technologies is critical, especially advanced batteries. Additional analysis and experience with the vehicle and systems can lead to further optimization as test data is applied to the design of motor and engine systems, and engine/motor coordination strategies are further refined.

Current Status

At this time, plug-in hybrid technology is at the prototype stage, although with excellent prospects for near-term commercial development. As one example, EPRI and DaimlerChrysler are working with several electric utilities and the South Coast Air Quality Management District to test a small fleet of PHEVs with advanced battery technology. These prototypes are undergoing testing in Germany and Los Angeles. They are demonstrating excellent performance, and have the potential to demonstrate long-term durability.

Current battery technology is also proceeding well. The most recent batteries demonstrate excellent safety, power performance, and laboratory life. Future challenges will include verifying lifetime testing in field testing, and developing production facilities to ramp up the availability of this technology.

Questions

What major research, development, and demonstration work remains on plug-in hybrid electric vehicle technologies? How should this work be prioritized?

What are the largest obstacles facing the widespread commercial application of plug-in hybrid electric vehicles and what steps need to be taken to address these hurdles (batteries, infrastructure, consumer preference, automotive inertia, cost-competitiveness, etc.)?

There are three main technical challenges which will need to be addressed in the commercialization of plug-in hybrid electric vehicles: first, proof of concept of high performance energy batteries capable of PHEV operation; second, the development of a robust supplier base for automotive electric motors and hybrid vehicle components; third, the coordination of a safe and usable set of charging standards.

The first and primary challenge is the validation of batteries capable of meeting PHEV operation requirements. This is a considerable challenge which has been under evaluation for many years, but this work has made tremendous progress and the batteries which are currently available in prototype form are capable of meeting PHEV requirements. Although more basic research can always be helpful, the best way to address the battery challenge is to increase testing of current pre-production technology and push forward towards meeting the production challenges.

The development of a robust supplier base is an important second step. Plug-in hybrid vehicles are generally similar to conventional hybrid vehicles, so an important first step is increasing the potential pool of component users and component suppliers so that economies of scale can be generated as quickly as possible. This is a broad effort that will have to be addressed on a nationwide basis.

The third challenge is the coordination of a safe and usable set of charging standards. Americans need to know that charging their vehicles is as safe and easy as charging their cell phones. This is the easiest challenge to meet from a technical standpoint, but it will require active participation from regulators, the automotive industry, and the electric power industry.

How does the Federal Government support the development of plug-in hybrid electric vehicle technologies? What can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles?

The most important question is what the Federal Government can do to help. The primary hurdle to plug-in hybrid development is the uncertainty of the market for electric transportation. In order to build batteries and components at a reasonable cost, considerable up-front capital investment is required. Although public comments by national leaders in support of PHEVs have been tremendously helpful, government can help further address this challenge by sending a clear signal that it supports this technology in the future. The following measures can be an important first step:

- Establish a program with the automotive manufacturers to create prototype demonstrations with a focus on near-term applications.
- Develop a plan for acquiring a fleet of plug-in hybrid electric vehicles in various configurations to be operated in multiple locations across the United States.
- As fleet data becomes available, collect and share the operating data to appropriately inform consumers and fleet operators about the benefits of plug-in hybrid technology.
- Direct the appropriate regulators to develop a certification test protocol for plug-in hybrid drive systems to maximize the benefits received by the manufacturer and consumer.
- Create an education program that informs the general public on the attributes of plug-in technology. In addition, create a program which reaches into the university level to educate science and engineering students on all types of electric-drive technology.
- Direct the national research programs to focus development on increasing the performance of batteries, electric drive systems, and power electronics. The Department of Energy recently held a summit laying out the research chal-

lenges; this effort should be fully funded and expanded as much and as soon as possible.

Does the discussion draft address the most significant barriers to the widespread adoption of plug-in hybrid electric vehicles?

EPRI has reviewed the discussion draft and is of the opinion that it addresses the most critical technical challenges to the development and adoption of plug-in hybrid vehicles. There is a high degree of correlation between the discussion draft and the six priorities listed by EPRI in response to the previous question.

How much additional energy demand could the electricity grid and utilities absorb if PHEV users decided to charge their vehicles in the middle of the day during peak power demand?

It is important to place the energy requirements of plug-in hybrids in perspective with current and projected U.S. electrical energy demands. A typical battery charger for a plug-in hybrid will draw about 1400 watts of power from a 120 volt outlet and be active for about two to eight hours per day. This is roughly equivalent to an electric space heater. Several analyses by EPRI or the DOE estimate the energy demand of plug-in hybrids, even at 50 percent market penetration, at between four and seven percent of total U.S. electricity demand. By 2050, total U.S. electrical demand is projected by the EIA to grow by almost 100 percent, 200 million plug-in hybrids (with an equivalent of 20 miles of electric range), driven and charged daily by their owners, would be responsible for approximately four to seven percent of this growth.

It will take many years to reach even this level of electrical energy consumption—the charging load from PHEVs will grow slowly and predictably. The total PHEV charging load is anticipated to be relatively consistent and electric utilities and system operators will be able to accurately monitor and react to the adoption of the vehicles.

What would be the likely net impact in criteria pollutant emissions and greenhouse gas emissions with the commercialization of PHEVs?

There are two primary components to the criteria pollutants of PHEVs—upstream emissions—produced by the refineries that produce the gasoline or diesel fuel and power plants that generate the electricity to recharge the batteries—and tailpipe emissions produced when driving the vehicles.

Utilities today operate under a number of different compliance requirements for criteria emissions. In many cases key pollutants are capped. The recent EPA Clean Air Interstate Rule (CAIR) has established new, lower limits on the emissions of SO_X and NO_X. The Clean Air Mercury Rule (CAMR) will set a strict limit on mercury emissions. When these federal regulations are combined with State and local requirements, the general result is that each year utilities must generate more and more energy while decreasing the total amount of pollutants generated. A historical review of electric sector emissions in the U.S. shows a steady growth in demand (typically one to two percent per year) alongside a steady decline in emissions.

There is significant potential for PHEVs to improve urban air quality by the elimination of a portion of the tailpipe emissions. PHEVs with a moderate ability to operate in an all-electric driving mode can reduce the emissions associated with "cold starts" of the combustion engine. These vehicles can also operate using only electricity for extended stop-and-go driving in cities or other congested areas.

The greenhouse gas emissions of a plug-in hybrid are the sum of tailpipe emissions from the combustion of fuel, refinery emissions, and power plant emissions. Plug-in hybrids use less hydrocarbon fuel and have lower refinery and tailpipe greenhouse gas emissions than either conventional vehicles or non-grid hybrids that are commercially available today. PHEVs have the added greenhouse gas emissions produced by generating electricity to recharge the battery.

Plug-in hybrids that are recharged from today's national electric grid will have 37 percent fewer GHG emissions than conventional cars and 13 percent fewer than comparable hybrids. However, it is more useful to look at the future characteristics of electricity in the U.S. when there would be significant numbers of PHEVs in the market.

The carbon intensity of the electric sector is declining year-over-year. This is due to several factors, including the retirement of old, inefficient fossil plants (many of which are more than 50–70 years old), construction of new more efficient power plants, and introduction of renewables and other non-emitting technologies. As the utility sector reduces carbon intensity, the greenhouse gas emissions of PHEVs that are recharged from this electricity will also decline.

The degree to which the electric sector reduces carbon intensity depends on a number of factors, including the rate of introduction and cost of new technologies, cost of different energy feedstocks, and governmental policy. EPRI has simulated a number of future cases for up to 200 million PHEVs in the U.S. by the year 2050 as part of our current work characterizing the emissions characteristics of plug-in hybrids. Each of these cases, including a "worst case" scenario of minimum technology introduction and no downward drivers on CO_2, resulted in a minimum GHG reduction of 44 percent compared to a conventional car.

BIOGRAPHY FOR MARK S. DUVALL

Mark S. Duvall is the Manager of Technology Development for Electric Transportation at the Electric Power Research Institute (EPRI), a non-profit organization whose mission is to provide collaborative science and technology solutions for the electric power industry.

Dr. Duvall conducts research and technology development efforts in advanced transportation, including hybrid system design, advanced energy storage, vehicle efficiency, systems modeling, and environmental analysis. His primary focus is plug-in hybrid electric vehicles and he oversees a number of EPRI research partnerships and collaborations with the automotive industry, State and federal agencies, national laboratories, and academic research institutions.

Dr. Duvall holds B.S. and M.S. degrees in Mechanical Engineering from the University of California, Davis and a Ph.D. in Mechanical Engineering from Purdue University.

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

May 16, 2006

Representative Judy Biggert
Chairman, Subcommittee on Energy
House Committee on Science
Suite 2320, Rayburn House Office Building
Washington DC, 20515-6301

Dear Chairman Biggert:

This is to provide a record of financial disclosure according to the Rules of the House of Representatives for testimony at your Subcommittee's hearing entitled, "Plug-in Hybrid Electric Vehicles" on Wednesday, May 17, 2006. I am the Senior Project Manager for the Electric Transportation Program at the Electric Power Research Institute, Inc. ("EPRI").

The following are the current federal funding contracts that directly support the subject matter on which I will testify before the Subcommittee:

Federal Sponsor	Period	Amount
1) National Renewable Energy Lab	2005-2006	$80,000
2) Federal Transit Administration Note: Subcontract from Alabama Automotive Fuel Cell Consortium	2004-2006	$1,566,250
3) Federal Transit Administration Note: Subcontract from Metropolitan Energy Center & Kansas City Area Transportation Authority	2003-2004	$500,000
4) Argonne National Laboratory Note: Not yet awarded	TBD	proposed $490,148

Please let me know if you require any further information regarding these federally funded contracts.

Sincerely,

Dr. Mark Duvall
Senior Project Manager

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Chairwoman BIGGERT. Thank you very much, Dr. Duvall.

Mr. German, you are recognized for five minutes.

STATEMENT OF MR. JOHN GERMAN, MANAGER, ENVIRONMENTAL AND ENERGY ANALYSES FOR AMERICAN HONDA MOTOR COMPANY

Mr. GERMAN. Yes. Good morning, Madame Chairman and Members of the Subcommittee.

Honda thanks you for the opportunity to provide our views on the subject of plug-in hybrid electric vehicles.

However, before beginning my testimony, I want to share with the Subcommittee several energy announcements Honda is making this morning.

First, Honda has established a goal to increase its industry-leading corporate average fuel economy by five percent from 2005 to 2010, resulting in a combined car and light truck CAFE fleet average of about 30.6 miles per gallon.

Second, we will introduce new diesel technology that achieves tier 2 bin 5 emission levels within the next three years without using Urea.

Third, we will introduce an all new and more affordable dedicated hybrid car with a goal of 100,000 sales in North America in 2009. These new commitments are part of our company's "2010 Vision: Commitment for the Future."

The automotive industry is in a period of unprecedented technology development. Gasoline development is still proceeding rapidly. The manufacturers are working hard on diesels that can meet the U.S. emission standards. Honda is producing third-generation hybrid electric vehicles, and most other manufacturers have also, or will be introducing hybrid electric vehicles.

Honda continues to make a dedicated compressed natural gas vehicle, the Civic GX, and a number of manufacturers are—produce flexible-fuel vehicles that run on gasoline or E–85.

Fuel cells are being heavily researched and developed, and plug-in hybrids are yet another advanced technology that merits further examination.

The development of all technologies is accelerating in response to growing concerns about energy security and global warming. Global demand for transportation energy is so immense that no single technology can possibly be the solution. There is no "magic bullet." We are going to need rapid development and implementation of as many feasible technologies as possible. But what is cutting-edge one day can quickly become outdated. And Honda, as well as other manufacturers, is constantly exploring a variety of technologies to achieve energy sustainability.

Thus technology-specific mandates cannot get us where we need to go. Performance requirements and incentives supported by research and development are much more effective.

Plug-in hybrids have a lot of promise, especially to displace oil consumption. However, plug-in hybrids and advanced batteries are still in the early stages of development. In that regard, the thrust of the draft legislation on research and development makes a great deal of sense.

The Subcommittee asked that I address the obstacles facing the widespread commercial application of plug-in hybrid vehicles and the steps that need to be taken. There are many issues that still need to be addressed. The extra batteries required for plug-in applications are heavy, decreasing performance, and take up valuable interior space. Plug-in systems must be safe and easy to use, and customer acceptance to plugging in the vehicle must be evaluated. Performance must be preserved, which means that either a larger, more costly electrical propulsion system must be installed, or the engine must be used for harder accelerations and higher speeds, which has potential emission implications.

From a societal point of view, there are additional issues with criteria pollutants and CO_2 emissions. How the electricity is generated will have a significant impact on benefits other than energy security.

While these are all legitimate issues that need further research, the issue of energy storage is much more significant. Although current hybrid vehicles have relatively small battery packs, the battery pack is still the largest single cost of the hybrid system. In addition, the energy flow in conventional hybrids is carefully monitored and controlled to ensure that the battery pack will last the life of the vehicle.

The battery pack for a plug-in hybrid must be many times larger. This adds thousands of dollars to the initial price of the vehicle and detracts from performance and interior space. Further, the battery pack is routinely discharged during electric-only operation and is subject to higher temperatures and rapid energy draws to maintain performance. This would cause much faster deterioration of the battery pack and a shorter battery life.

The lithium-ion battery is being promoted by some as the answer to these challenges. However, despite intense development of lithium-ion batteries for many years, durability has not been proven, they are more susceptible to damage than nickel metal hydride, and they do not perform well in cold or hot environments. End-of-life battery disposal may be a larger issue for lithium-ion than for nickel metal hydride, as the raw materials in the nickel metal hydride battery are much more valuable.

Cost effectiveness is the major issue. Even at $3 per gallon and including the cost of electricity to recharge the battery pack, adding plug-in capacity to a conventional hybrid car would initially cost about $3,000—I am sorry, would save about $3,000 over the vehicle lifetime. These energy savings would likely be offset just by the initial incremental costs of the additional batteries, even in high-volume applications. If you add in the costs of shorter battery life, lower performance, less interior space, off-board charging systems, plus the customer discounting of fuel savings, customer acceptance is going to be a major challenge unless fuel prices rise to substantially more than $3 per gallon, fuel shortages occur, plug-in hybrids are heavily subsidized, or there is a breakthrough in energy storage.

Thus, by far, the most important action the government can take is research into improved energy storage. Honda strongly supports the research program outlined in the House plug-in discussion draft. Hybrids, including plug-in hybrids, have a great deal of promise, and the potential issues should be adequately investigated for solutions, especially energy storage. Until improved batteries can be developed, there is little need to assess customer acceptability or conduct vehicle demonstration projects.

As Dr. Duvall mentioned, the Department of Energy held a workshop on plug-in hybrid electric vehicles on May 4–5. This was an excellent workshop, and I request that the paper be used as the basis for the workshop you submitted for the record. The Department of Energy's work in this area should be supported and funded by Congress.

I appreciate the opportunity to present Honda's views, and I would be happy to answer any questions.

[The prepared statement of Mr. German follows:]

PREPARED STATEMENT OF JOHN GERMAN

Good morning Madam Chairwoman and Members of the Subcommittee. My name is John German and I am Manager of Environmental and Energy Analysis with American Honda Motor Company. We thank you for the opportunity to provide Honda's views on the subject of plug-in hybrid electric vehicles.

The automotive industry is in a period of unprecedented technology development, encompassing everything from gasoline engines and transmissions to diesels, hybrid-electric vehicles, fuel cells, and vehicles powered by alternative fuels. The efficiency of the conventional gasoline engine has improved by 1.5 to two percent per year for the last 20 years, although these gains have largely gone into features more highly valued by customers than fuel economy, such as performance, utility, luxury, and safety. Gasoline technology development is still proceeding rapidly, with variable valve timing, direct fuel injection, variable cylinder displacement, and turbocharging all on the horizon. Diesel engines have also seen dramatic improvement in recent years and manufacturers are working hard to meet the U.S. emission standards. Hybrid-electric vehicles are in their second and third generation at Toyota and Honda and most other manufacturers have also or will be introducing hybrid-electric vehicles. Honda continues to market a dedicated compressed natural gas vehicle, the Civic GX, and is backing it with development of a home natural gas refueling system developed by Fuelmaker, called PHILL. A number of manufacturers produce flexible-fuel vehicles that run on gasoline or E–85. Development of battery-electric vehicles continues and they have found a niche in neighborhood vehicles for closed communities. And, of course fuel cells are being heavily researched and developed. Different companies are working on different technologies, which is the optimal way and makes good use of competition.

Development of all technologies is accelerating in response to growing concerns about energy security and global warming. Global demand for transportation energy is so immense that no single technology can possibly be the solution. Fuel cells might be the final solution someday, but the challenges of hydrogen production, transport, and storage will take a long time to solve and implement, especially on the volume demanded for transportation worldwide. Biofuels are promising and can replace some fuel use, but even development of cellulosic ethanol only has the potential to displace, at most, 10 to 20 percent of the world's oil demand. The point is that there is no magic bullet—we are going to need rapid development and implementation of as many feasible technologies as possible. Honda is developing technology that meets both the needs of our customers and those of society. What was cutting edge one day can quickly become out dated. Thus we are constantly exploring a variety of technologies to achieve energy sustainability.

Given the rapid changes in technology, performance-based incentives are the best way to move the ball forward. It is impossible to predict the pace of technology development and when breakthroughs will or will not occur. Accordingly, technology-specific mandates cannot get us where we need to go. In fact, previous attempts to mandate specific technologies have a poor track record, such as the attempt to promote methanol in the 1990s and the California electric vehicle mandate. The primary effect of technology-specific mandates is to divert precious resources from other development programs that likely are much more promising. If there are to be mandates, they should be stated in terms of *performance* requirements, with incentives and supported by research and development.

With respect to plug-in hybrids, it is really too early in the development of hybrid vehicles and advanced batteries to predict whether plug-in vehicles will reach their hoped-for potential. Plug-in hybrids have a lot of promise, especially to displace oil consumption. They need and deserve further research and development. In that regard, the thrust of the draft legislation makes a good deal of sense. Before plug-in vehicles can be viable, however, there are a number of technology, consumer acceptance, environmental and cost issues that still need to be addressed.

A. Battery Weight and Size and Motor Performance Demands

The extra batteries add 175 to 500 pounds to the vehicle, which decreases performance, and it is difficult to find space for the extra batteries without detracting from the utility of the vehicle. Systems to plug the vehicle in to the electric grid must be safe and easy to use. Customer reaction to having to plug in the vehicle is largely unknown. Performance must be preserved, which means that either the electric motor and energy storage must provide performance equivalent to the engine; or the engine must be started and used with the electric motor for harder accelerations and higher speeds.

If the engine is not turned on for high accelerations, the vehicle is entirely dependent on the electrical system for acceleration. This requires a much larger electric motor and power electronics, which adds cost and weight and requires more cooling. The high electrical demand during high accelerations also generates high battery temperatures and accelerates battery deterioration. Adding an ultra-capacitor to handle the high loads might solve the battery problem, but this adds yet more cost and takes up additional space.

If the engine is turned on only during high accelerations, emissions become a major issue. Catalytic converters are used to reduce most of the harmful emissions from the engine. However, these converters must be at least 350 degrees Centigrade (660 degrees Fahrenheit) to function properly. If the engine is off most of the time, catalyst temperatures will drop well below the level needed for conversion of emissions and tailpipe emissions will be orders of magnitude higher. Also note that current emission and fuel economy test procedures are not designed to accurately measure emissions from these types of vehicles and would have to be revised.

B. Energy Storage

However, while these are all legitimate issues that need further development, the issue of energy storage is the most significant. Some industry analysts have been critical of hybrids because they cost more and the fuel savings are not recoverable in the short term. Although current hybrid vehicles have relatively small battery packs, the battery pack is still the single largest cost of the hybrid system. Further, energy flow in conventional hybrids is carefully monitored and controlled to ensure maximum battery life. The battery state-of-charge is never allowed to rise above about 80 percent or drop below about 20 percent, where more deterioration occurs. Battery temperatures are carefully monitored at many points inside the battery pack and battery assist and regeneration is limited when necessary to keep the temperature at levels that ensure low deterioration. Also, the duty cycle of a conventional hybrid usually just changes the battery state-of-charge by a few percent of the total energy capacity. As a result of these efforts, the NiMH battery packs in current hybrid vehicles are expected to last the life of the vehicle.

The battery pack must be many times larger for a plug-in hybrid, even with just a 20-mile electric range. This adds thousands of dollars to the initial price of the vehicle, not to mention the impact the extra batteries have on weight and interior space. Further, the battery pack is now subjected to deep discharge cycles during electric-only operation and to much higher electrical loads and temperatures to maintain performance. This will cause much more rapid deterioration of the battery pack, likely requiring replacement of the battery pack at least once during the vehicle life.

The lithium-ion battery is being promoted by some as the answer to these challenges. Lithium-ion has the promise to increase energy and power density compared to NiMH, perhaps by as much as 100 percent, which would reduce the weight and size impacts. However, despite intense development of Lithium-ion batteries for many years, durability has not been proven, they are more susceptible to damage than NiMH, and they do not perform well in cold or hot environments. Additionally, Lithium-ion batteries are expensive and may not offer significant cost savings compared to NiMH batteries.

C. Cost Effectiveness Challenge

Let's examine the real world economic problem posed by the battery storage issue using a specific example to help illustrate the issues. According to statements made by Mark Duvall of EPRI at the SAE Government/Industry Meeting on May 10, about 40 percent of the duty cycle of a plug-in hybrid should be electric-only operation. For a typical vehicle lifetime of 150,000 miles, this means that about 60,000 miles will be accumulated while the battery is being charge depleted. For a vehicle with an all-electric range of 20 miles, this requires that the battery pack be able to tolerate 3,000 deep discharge cycles without significant energy or power storage deterioration. Note that assumptions about the proportion of operation in charge-depleting mode directly affect the number of deep discharge cycles that the battery pack must be able to tolerate. For example, if the vehicle operates in charge-depleting mode 60 percent of the time, the battery pack will be used for 90,000 miles and it must be able to tolerate 4,500 deep discharge cycles or it will need to be replaced. 3,000 deep discharge cycles is the current goal for Lithium-ion batteries, but it has not been proven yet, especially under the range of temperatures and operating conditions experienced in the real world.

For our example, let us assume that the starting point for a plug-in hybrid is the Toyota Prius. Real world fuel economy for the Prius is in the 45–50 mpg range. To be conservative, we will assume 45 mpg. Thus, for 150,000 miles, the Prius will use 3,333 gallons of fuel. If 40 percent of the mileage on the Prius is in charge-depleting mode, then the fuel savings will be 40 percent of 3,333 gallons, or 1,333 gallons.

Even at $3 per gallon, the fuel savings for a plug-in vehicle like the Prius is only $4,000 over the average vehicle lifetime. After factoring in the electricity cost to recharge the battery pack, which would be at least $1,000, the net savings to the consumer is less than $3,000. Even if the Lithium-ion battery meets all of its targets, the incremental cost of just the additional batteries in high volume applications would be close to the lifetime fuel savings. This ignores the tradeoff between electric motor size and emissions, the performance penalty from the additional weight of the batteries, the space needed for the batteries, the higher deterioration rate and increased risk of battery replacement due to the deep discharge cycles, and the cost of safe off-board charging systems. From a manufacturers' and customers' point of view, there is no business case unless fuel prices rises to substantially more than $3 per gallon, fuel shortages occur, plug-in hybrids are heavily subsidized, or there is a breakthrough in energy storage. By far the most important action the government can take is research into improved energy storage.

Until improved batteries can be developed with lower cost and better durability, there is little need to assess customer acceptability or conduct vehicle demonstration projects. However, customer discounting of fuel savings is a potential long-term barrier that eventually will need to be overcome. While some customers value fuel savings more highly, the average new vehicle customer only values the fuel savings for roughly his or her period of ownership, or about 50,000 miles. This means that, at $3 per gallon, the average new vehicle customer would only value a plug-in hybrid at about $1,000. Of course, this would change dramatically if fuel shortages were to occur. The government may also wish to explore ways to incentivize the full useful life savings to manufacturers or customers.

D. Environmental Considerations

From a societal point of view, there are additional issues with criteria pollutants and CO_2 emissions. How the electricity is generated will have a significant impact on benefits other than energy security. If coal is the primary source of the energy, criteria pollutants and CO_2 emissions will be higher with the plug-in hybrid. If renewable sources of energy are used to generate the electricity, plug-in hybrids can offer benefits for clean air and global warming. Another societal issue is end-of-life battery disposal. This is not likely to be a problem for NiMH batteries, as the raw materials are very valuable and recyclers will be active in setting up systems to recycle the batteries. However, it may be a problem for Lithium-ion batteries, where the raw materials are far less valuable. These are all additional areas for research.

E. Additional Research Is Needed

Honda strongly supports the research program outlined in the House discussion draft of the *Plug-In Hybrid Electric Vehicle Act of 2006.* Hybrids, including plug-in hybrids have a great deal of promise and their potential issues should be actively investigated for solutions, especially energy storage. The outlined research program is the best way for the Federal Government to accelerate the development and deployment of plug-in hybrid electric vehicles.

Fortunately, the Department of Energy is already developing plans to identify plug-in hybrid research needs and solutions. The Department of Energy held a Workshop on Plug-in Hybrid Electric Vehicles on May 4–5, 2006 to discuss issues and questions on plug-in hybrid research needs. The paper issued in advance of the workshop presented an excellent outline of the advantages of plug-in hybrids, the challenges faced, especially energy storage, the technical gaps, and the questions that need to be answered. The paper is an excellent resource for planning future research and development for plug-in hybrids and should be read by everyone interested in promoting plug-in hybrid vehicles. The Department of Energy's work in this area should be supported and funded by Congress.

I appreciate the opportunity to present Honda's views and would be happy to address any questions you may have.

BIOGRAPHY FOR JOHN GERMAN

John German is Manager of Environmental and Energy Analyses for American Honda Motor Company. His responsibilities include anything connected with environmental and energy matters, with an emphasis on being a liaison between Honda's R&D people in Japan and regulatory affairs.

Mr. German has been involved with advanced technology and fuel economy since joining Chrysler in 1976, where he spent eight years in Powertrain Engineering working on fuel economy issues. Prior to joining Honda eight years ago, he spent 13 years doing research and writing regulations for EPA's Office of Mobile Sources' laboratory in Ann Arbor, MI. Mr. German is the author of a variety of technical papers and a book on hybrid gasoline-electric vehicles published by SAE. He was the first recipient of the recently established Barry D. McNutt award, presented annually by SAE for Excellence in Automotive Policy Analysis.

He has a Bachelor's degree in Physics from the University of Michigan and got over halfway through an MBA before he came to his senses.

Chairwoman BIGGERT. Thank you very much, Mr. German.

Dr. Ricketts, you are recognized.

STATEMENT OF DR. S. CLIFFORD RICKETTS, PROFESSOR, AGRICULTURAL EDUCATION, SCHOOL OF AGRIBUSINESS AND AGRISCIENCE, MIDDLE TENNESSEE STATE UNIVERSITY

Dr. RICKETTS. Thank you for the opportunity to be here today.

I want to focus my comments on flex-fuel. It was mentioned in the draft legislation, but it—and you mentioned it, I think, once in your opening statement, so all the things that I say today is going to pyramid in to flex-fuel.

I believe the help with the high fuel costs lies in plug-in flex-fuel, and I emphasize flex-fuel hybrid vehicles. I believe the legislation is on track, but I believe it can do more.

Now let me explain my rationale.

I have been working with alternative fuel since 1978. In the early 1970s and 1980s, we did an ethanol engine, ran ethanol from corn. Our whole objective was to make the American farming energy independent in the time of a national crisis. That is why an ag. boy is here against these heavyweights today from the agricultural production point of view.

After we ran an engine off of corn, our next endeavor was to run engines off cow manure. Well, that was from methane. That actually led to my next goal, and that was running engines off of water. On October 14, 1987, we ran our first engine for eight seconds off of hydrogen from water. Four years later, we set the land speed record at the Bonneville Salt Flats with our hydrogen vehicle and held it for several years. Then we ran an engine off soybean oil, now called soy diesel. And actually, I didn't know it was called that in 1991, but we had a flex-fuel vehicle in 1991 that ran off hydrogen, propane, and gas, or a combination of any of those fuels. And then one of our latest things was to run an electric vehicle.

However, my ultimate goal has always been to run engines off water, specifically sun and water.

Now that brings us up to where we are today, and let me talk about the plug-in flex-fuel vehicle, because I think this legislation, from a personal point of view, brings my research into focus from the last 25 to 30 years. Everything that we have done so far can be pyramided into this flex-fuel plug-in hybrid vehicle. I believe we can have some legislation, again, by beefing up the flex-fuel part. It was only eluded to in a couple of places, so let me briefly say that what we are doing now, my vision for the future and why flex-fuel is important to be added to this legislation.

Now Representative Gordon mentioned earlier that we are running engines off of sun and water. Let me tell you how we are doing this.

We installed a 10-kW cylinder unit through the Green Switch program with Tennessee Valley Authority. It goes into the Murfreesboro Electric Gridline, which is under the umbrella of TVA. Now with the aide of automatic readings and computers and calculations and so forth, all of the electricity is monitored. Since the unit was started March 9, 2004, that little unit has produced over 28,000 kilowatts. The system works analogous to the banking system. The energy is stored in the bank for use at any time, day or night, sunny or cloudy. And when the electric component plug-in of the electric hybrid is charged, the kilowatts used are counted through another meter. So in other words, the electricity is taken from the bank, and an immediate balance is also available by comparing the difference in the input meter and the output meter. The present kilowatt balance is 24,000.

Now, when I am starting to do this, I wanted to run the electric component directly off the solar unit. I wanted to run the hydrogen component directly off the solar unit, but I was talked out of it, and I am glad I was. I would have lost 90 percent efficiency.

Chairwoman BIGGERT. Dr. Ricketts, your microphone seems to be cutting out. Maybe if you could just turn it, this part of it, up a little bit more. No, like this. Yeah, and then pull it a little bit closer to you.

Dr. RICKETTS. Okay.

Chairwoman BIGGERT. Okay.

Dr. RICKETTS. How are we doing now? Okay.

People think you have to have a solar panel on a vehicle for it to be a solar vehicle. Actually, you don't. As explained earlier, once you bank it into the grid, once the vehicle is charged, the electricity is taken from the bank. Let us say we have to travel to an adjoining county that has a different electric co-op. This hasn't been developed. This is creative stuff. By using a barcode system, the electric charge of kilowatts could be used to transfer the visited electric co-op to your home-based co-op. The amount would be charged against you, or taken from your bank. Now this can work for solar. It can work for wind. It can work for some other alternative fuels.

Now the same process works with the hydrogen or water component. A similar procedure occurs when the hydrogen is produced. The kilowatts needed to power the electrolysis is metered. The banked electricity powers the electrolysis unit which separates the hydrogen from the water. It goes through several processes that I won't bore you with, but eventually, it is compressed and fills an on-board 5,000 psi carbon wrapped tank.

So by using the system described above, vehicles are driven only with sources of sun and water.

So in conclusion, by adding the flex-fuel part of the legislation to the plug-in, we could use gasoline, that is what we are trying to get away from obviously, a plug-in, a solar, a wind, or ethanol, or hydrogen with this legislation that we are proposing. The thing that I couldn't figure out was how to run an internal combustion spark-ignited engine off soy diesel. So with the flex-fuel hybrid technology in place as our near innovative technologies come on of sun and hydrogen, and as they continue to gain momentum, the infrastructure, the vehicle technology will already be in place.

Thank you.

[The prepared statement of Dr. Ricketts follows:]

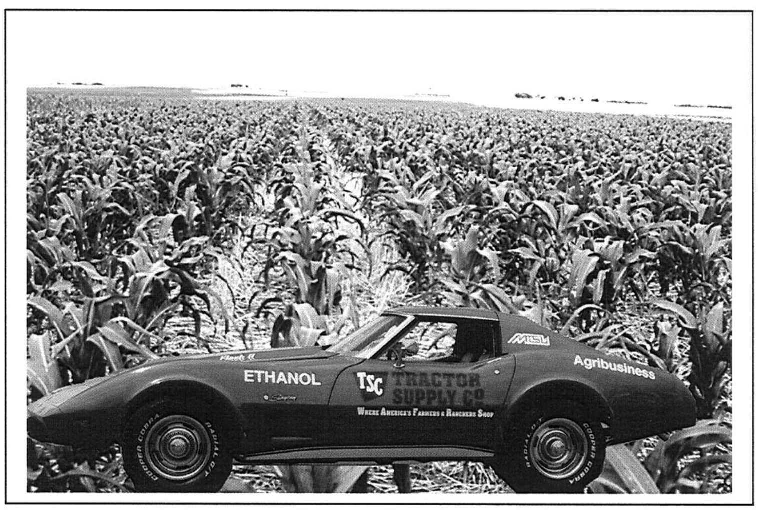
PREPARED STATEMENT OF S. CLIFFORD RICKETTS

Alternative Fuel: Past, Present, and Future (Plug-in Flex-Fuel Hybrid Electric Vehicles)

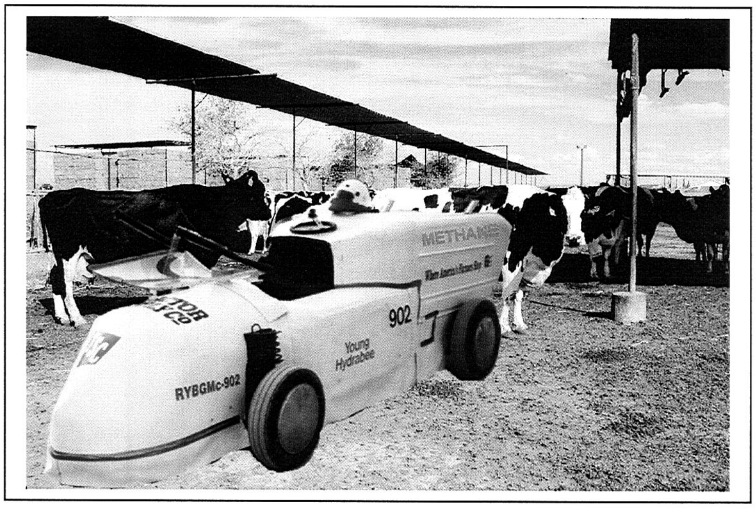
PAST

Work on alternative fuel began at Middle Tennessee State University (MTSU) in 1979. The work was spurred by the fact that the Iranians had taken hostages, and OPEC was attempting to control the world's fuel (petroleum) supply. Out of frustration, the author and his students started the conquest for the American farmer to be energy independent in the time of global crisis.

Running an engine off corn (ethanol) was the first challenge. Although many other persons or groups were doing similar research making ethanol, it was the persistency of the MTSU team that eventually led to the building and running of an ethanol-powered truck that ran over 25,000 miles on pure ethanol. Presentations were made at the 1982 World's Fair and TVA's 50th Anniversary Barge Tours.



Having succeeded in building an ethanol-powered vehicle, the next challenge was to run an engine off cow manure (methane). Once hydrogen sulfide and carbon dioxide are removed, the gas which remains is CH_4 (natural gas). Natural gas engines were fairly common, and several engines were reviewed that ran off methane. It was found that methane production was viable and methane digesters were available in selected large dairy farms.



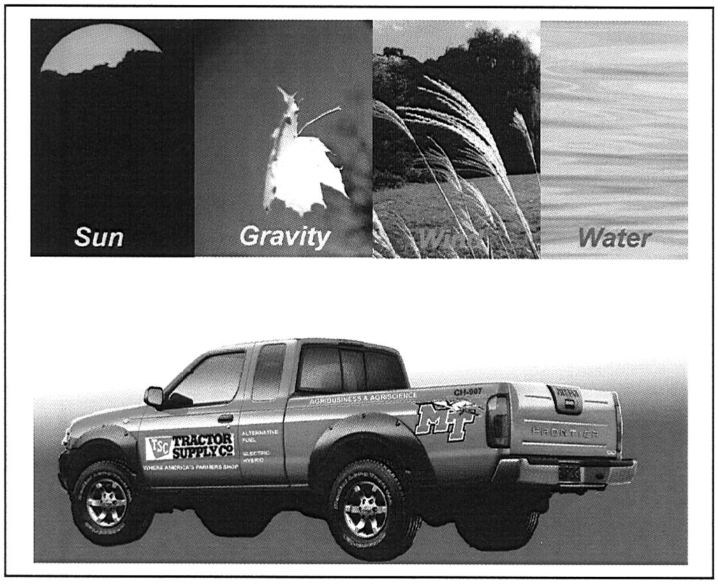
The knowledge gained in the study of methane production lead to the ultimate challenge; to run an engine off hydrogen from water. On October 14, 1987, the MTSU team ran an engine for eight seconds off hydrogen from water. The next day they ran the eight horsepower engine for two minutes.

Since that time, the author and his students have run tractors, cars, trucks, and stationary engines off hydrogen. The MTSU team was invited to the world's first hydrogen race at the 1991 Bonneville Speed Trials at the Great Salt Flats in Wendover, Utah, where they set the world's land speed record (timed only) for a hydrogen vehicle. Researchers at MTSU proceeded to build another engine to run off pure hydrogen. The MTSU team entered the vehicle in the Southern California Timing Association (SCTA) World Finals on October 18, 1992, at the Bonneville Salt Flats in Wendover, Utah, and set a new world land speed record for pure hydrogen-fueled vehicles. The record stood for several years.

The next fuel to be tested was soybean oil. An Allis-Chambers diesel tractor engine was placed in a 1975 Corvette. The author and his students placed fourth of 40, behind two entries by NASA and one from American Honda, in an alternative fuel road rally sponsored by the Florida Solar Energy Commission and others. The rally started at Cape Canaveral and ended at Disney World. A clogged fuel line resulted from the decomposition of soybean oil. Soybean oil breaks down after six months.

PRESENT

The lifetime goal of the MTSU research is to run engines off sun and water (hydrogen from water). This is presently happening at Middle Tennessee State University. An electric/hydrogen hybrid truck is presently being developed. The electric component (plug-in) is complete, and the internal hydrogen combustion engine generator set is complete. The range and on-board charging system is in the process of being tested.



The following explains how to run engines off sun and water.

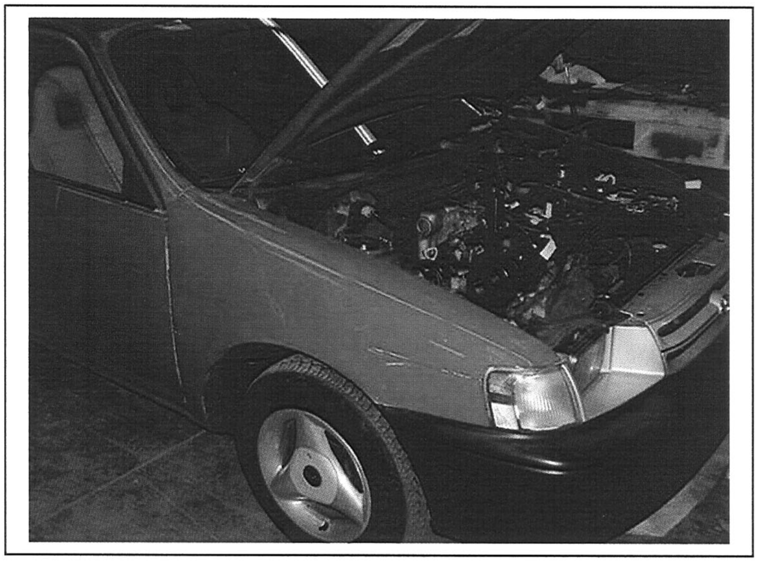
Sun

A 10-kilowatt unit was installed. The unit was installed by Big Frog Mountain Energy. Through the Green Power Switch program with the Tennessee Valley Authority (TVA), the electricity produced by the solar array goes into the Murfreesboro Electric Grid Lines within TVA. With the aid of automatic computer readings and calculations, all the electricity produced is monitored. Since the 10-kilowatt solar unit was started March 9, 2004, over 28,000 kilowatts have been produced.

The system works analogously to the banking system. The energy is stored in the "bank" for use at any time—day or night, sunny or cloudy. When the electric component (plug-in) of the electric hybrid truck is charged, the kilowatts used are counted through another meter. In other words, the electricity is taken from the bank and an immediate balance is also available by comparing the difference in the input meter and output meter. The kilowatt balance is presently over 24,000. This is enough stored kilowatts to drive from New York City to Los Angeles, approximately four road trips. The "plug-in" component of the hydrogen/electric hybrid truck uses approximately one kilowatt per mile.

Water (Hydrogen)

A similar procedure occurs when the hydrogen is produced. The kilowatts needed to power the 40 cubic foot per hour electrolysis unit is metered. The unit is a Proton 40 electrolysis unit from the Proton Energy Company. The banked electricity powers the electrolysis unit which separates the hydrogen and oxygen from the water. The hydrogen is then temporarily stored in two 500-gallon tanks at 200 psi. Another system, constructed by General Hydrogen, Gallatin, Tennessee (U.S. headquarters), compresses the hydrogen to fill the 4–K cylinders at 6,500 psi. Using a cascading system, a 5,000 psi (4.2 kilogram) hydrogen tank is filled on-board the hydrogen electric/hybrid truck. (NOTE: We also have three hydrogen internal combustion engine cars which can run off sun and hydrogen from water.)



By using the system just described, vehicles are being driven with the only power sources being sun and water. Please note that both the electric component of the truck and the hydrogen component of the truck could be powered directly from the solar unit. However, approximately 90 percent of the electricity produced would be lost. By banking the electricity through the grid, the solar unit is working and saving any time the sun is shining and somewhat when it is cloudy. Time has not permitted energy cost calculations as of today.

FUTURE

I believe the alleviation of the future U.S. energy crisis lies within Plug-in Flex-Fuel Hybrid Vehicles. I will explain my rationale. At Middle Tennessee State University, as mentioned before, we are running engines off sun and/or water. We are working on a vehicle that runs off most any fuel. The vehicle is a plug-in hybrid but not in the sense that modern hybrids are once they have the proper adaptation kits. Here is my vision for the future, with the versatile use of PHEVs.

*__Option 1 (Plug-in wall outlet)—__The plug-in hybrid can be driven on short trips of 20–40 miles simply by plugging into either a 110- or 220-watt outlet. You get a quicker and deeper charge with 220 current.

*__Option 2 (Make it a solar car)—__We are doing this at Middle Tennessee State University. People think that you have to have a solar panel on a vehicle for it to run off the sun. This is not true. As explained earlier, the 10-kilowatt solar unit that we have installed at MTSU produces electricity and stores it ("banks it") into the electric grid. Once the vehicle is charged, the stored electricity is taken from the "bank." Let us say that we have to travel to an adjoining county that has a different electric cooperative. By using a bar code system, the electrical charge or kilowatts used could be transferred from the visited electric cooperative to your home-based electric cooperative. The amount would be charged against, or taken from, your "banked" amount. For example, the University is a member of the Murfreesboro Electric Cooperative, but my home residence is served by Middle Tennessee Electric. Nashville (32 miles away) is a part of Nashville Electric Service. Electric plug-ins could be installed in selected parking lots with the appropriate bar code system. This way, people could drive their cars off solar energy without having a solar unit on board the vehicle. Obviously, the same principle would work with wind generators.

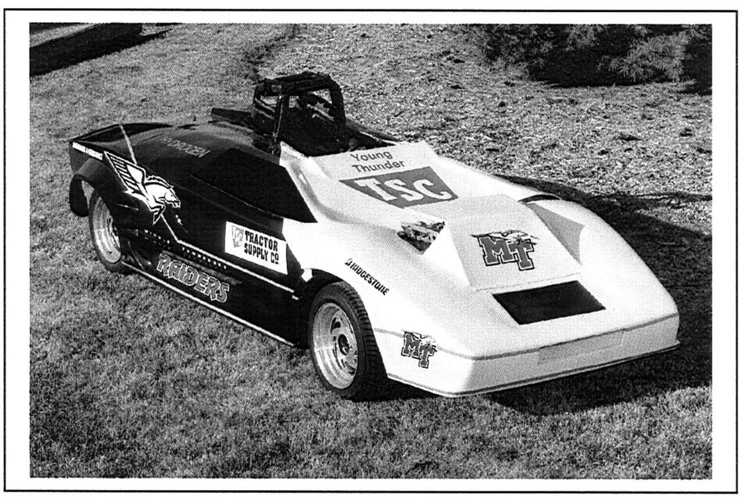
***Option 3 (Gasoline)—**For trips with a range over 20–40 miles, the internal combustion engine starts charging the system and the vehicle works like a normal hybrid. Even though we are using gasoline, our electric utilities are saying the electricity to move a plug-in hybrid electric vehicle (PHEV) down the road costs about one-third the cost of the equivalent gasoline at today's prices.

***Option 4 (Ethanol—E–85)—**A flex-fueled vehicle that uses spark plugs can run off practically anything except diesel fuel and any oil-based alternative fuels (soybean oil, cooking oil, etc.). Ford Motor Company has the Ford F–250 Super Chief that can run off hydrogen, gasoline, or E–85 ethanol fuel. Option 4, ethanol, would be used as an alternative to gasoline.

Using E–85 instead of gasoline is also good for the environment because it generates 30 percent less carbon monoxide and 27 percent less CO_2 than a comparable gallon of gasoline, and most of that CO_2 is carbon cycle neutral because it is derived from plants which need CO_2 to grow. (E–85 generates 17.06 pounds of CO_2 to create 15,500 BTUs compared to the 23.95 pounds for gasoline.) *(www.evworld.com/electrichybrid.cfm)*

***Option 5 (Hydrogen from water, separated by the sun)—**This process was explained earlier. I really believe that the fuel of the future is hydrogen and sun. (NOTE: From an agriculture point of view, I am for ethanol from corn and soybean oil as fuels. However, realistically, I believe they are only short-term solutions. I believe the price of corn and soybeans in five to ten years will become so expensive due to agriculture economics (supply and demand) that these products will be cost prohibitive as a fuel stock. I don't have a "handle" on the potential of switch grass and other cellulose materials.)

With the flex-fuel hybrid, the automotive technology will already be in place while the hydrogen technology continues to gain momentum. Realistically, sun and water are the most viable fuel alternatives. Once they are gone, we will have no need for fuel anyway.



Answers to Specific Questions About PHEVs

1. What major research, development, and demonstration work remains on plug-in hybrid electric vehicle technologies? How should this work be prioritized?

The biggest obstacles are conversions of the existing hybrids to become plug-in hybrids. The cost of most conversions listed on the Internet was approximately $10,000. It seems reasonable that if the automotive companies engineered the cars as PHEVs, the cost should not be much more than the price of conventional hybrids currently coming off the assembly line.

I believe the priority on PHEVs should be developing flex-fuel PHEVs. The rationale for this was given earlier. There are so many options on alternatives to the purchase of foreign oil with flex-fuel PHEVs. There are also environmental and other implications.

2. What are the largest obstacles facing the widespread commercial application of plug-in hybrid electric vehicles, and what steps need to be taken to address these hurdles (batteries, infrastructure, consumer preferences, automotive inertia, cost-competitiveness, etc.)?

Three issues need to be mentioned:

First, the development of the perfect battery is always an issue and a challenge. If the perfect battery had already been developed, it would have a range of 300–350 miles with a 15-minute charging time at an affordable cost. Obviously, we are not there. However, nickel cadmium, nickel-metal hydride batteries, and lithium-ion are very adaptable and would work quite well with PHEVs. One battery engineer told me to give him the range needed and he could build the battery. On the other hand, the cost would probably be prohibitive.

The second issue would be cost competitiveness. Presently, hybrids are around $4,000 more than an equal counterpart. A PHEV would be around $6,000 more than a regular car. It seems that a flex-fuel PHEV would be even higher, but I have no data for proof.

The third issue would be infrastructure. Charging at home would not be a problem; but charging at work, while shopping, or while on simple leisure trips could pose a problem. Coin-operated charging meters would need to become commonplace. While visiting the University of Alaska at Fairbanks last summer, I noticed the electrical outlets at nearly every parking spot. These were a necessity for block heaters on the vehicles with the -50° temperatures in the winter. Yet, it was a part of the infrastructure in Fairbanks, Alaska.

3. How does the Federal Government support the development of plug-in hybrid electric vehicles technologies? What can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles?

I am not aware of any direct federal funding of plug-in electric hybrids. Indirectly, converted PHEVs have been at U.S. Energy Department-sponsored "Future Truck" competitions. Also, General Dynamics built the U.S. Marine Corps' diesel-electric PHEV–20 HUMVEE.

The Federal Government can offer grants to develop a more economic conversion kit. Secondly, automotive companies need some incentive to build PHEVs. Thirdly, customers that buy PHEVs or flex-fuel PHEVs could be offered a tax credit between the difference in cost of a regular automobile and a PHEV or flex-fuel PHEV.

4. Does the discussion draft address the most significant technical barriers to the widespread adoption of plug-in hybrid electric vehicles?

Yes. However, I do not believe we should overlook the internal combustion engine for hydrogen. Hydrogen can work with a flex-fuel vehicle. Fuel cells are great, but the cost makes them a non-issue for several years. The minimum cost for any fuel cell strong enough to power a highway vehicle would be $55,000 plus the price of the vehicle. Presently, the cost of construction for a fuel cell is around $700 per kilowatt (1.2 horsepower) compared to $50 per kilowatt for an internal combustion engine.

5. Would commercial applications of PHEVs be delayed by incorporating flexible fuel capabilities?

I suspect that the commercial applications of PHEVs might be delayed a year or two. As stated earlier, Ford Motor Company already has a flex-fuel vehicle and a hybrid. I suspect other manufacturers are close behind. Since the present hybrids have to be redesigned and engineered to offer the plug-in options, it may take the same amount of time to develop their flex-fuel vehicle hybrids.

BIOGRAPHY FOR S. CLIFFORD RICKETTS

Dr. S. Cliff Ricketts is a Professor of Agricultural Education and Acting Director in the School of Agribusiness and Agriscience at Middle Tennessee State University, Murfreesboro, Tennessee.

Dr. Ricketts has been involved with alternative fuel research since 1978. He and his students have designed and built engines powered from a variety of sources, including ethanol, methane, soybean oil, hydrogen, solar/electric, and hydrogen/electric hybrid.

Financial Disclosure: I have not received federal funding on these projects. The funding that I received in 2005-2006 includes:

Corporate Sponsor/Partnership-Tractor Supply Company	$9,500
MTSU Match	$9,500
Basic and Applied Sciences	$2,500
School of Agribusiness and Agriscience	$5,000
TOTAL	$26,500

Other funding:

One time TAF Funds (Technology Access Funds - 2001)	
Electrolysis Unit	$70,000
One time TAF Funds (Technology Access Funds - 2003)	
10 Kilowatt Solar Unit	$70,000
TOTAL	$140,000

Chairwoman BIGGERT. Thank you very much, Dr. Ricketts.

Now Dr. Santini, who—are you still living in Downers Grove?

Dr. SANTINI. I am in Westmont now.

Chairwoman BIGGERT. Okay. You are still in my district, so——

Dr. SANTINI. Right.

Chairwoman BIGGERT.—I am glad for that.

Thank you.

You are recognized for five minutes.

STATEMENT OF DR. DANILO J. SANTINI, SENIOR ECONOMIST, ENERGY SYSTEMS DIVISION, CENTER FOR TRANSPORTATION RESEARCH, ARGONNE NATIONAL LABORATORY

Dr. SANTINI. Thank you.

Madame Chairwoman, Representative Honda, Members of the Subcommittee, thank you very much for your invitation to testify.

I respond to your request to answer several questions and discuss the draft bill the *Plug-In Hybrid Electric Vehicle Act of 2006.*

Your first question was what major research, development, and demonstration work remains on plug-in hybrid electric vehicle technologies, and how should this be prioritized.

I believe that the highest priority is that Congress and the Department of Energy make a long-term commitment to research and development of lithium-ion batteries, in particular, and energy storage, in general, with the focus on needs of plug-in hybrids. The "Discussion Issues and Questions" white paper distributed at the Department of Energy's May 4–5 workshop on plug-in hybrid electric vehicles, which I have included with my written testimony, stimulated discussion of plug-in priorities. The participating national and international experts have provided excellent guidance on research priorities. The consensus view of participants was that plug-in hybrids belong in the research portfolio of the Federal Government.

The second question was what are the largest obstacles facing the widespread commercial application of plug-in hybrid electric vehicles, and what steps need to be taken to address these hurdles.

I quote the DOE workshop white paper "battery technology could be a showstopper for plug-in hybrids." Lithium-ion batteries are superior to nickel metal hydride in terms of specific energy and specific power, but are not yet competitive in cost per kilowatt hour per unit of energy. Because of increasing materials cost for nickel metal hydride batteries and steady power increases and cost per kilowatt reductions, lithium-ion batteries may soon be used in hybrids, but low costs per kilowatt hour are needed for plug-in hybrids to succeed. Simple adaptation of current parallel hybrids will not allow consumers to drive all electrically with performance suitable for universal use. Top all-electric operation speeds would not match current urban and highway test speeds. The need to fully deplete batteries will reduce battery life relative to conventional hybrids. There are multiple component alterations and control systems adaptations possible to eliminate or reduce these limitations but at a cost. Perhaps these would increase marketability, perhaps not.

A key question is whether we should ever expect or require a plug-in hybrid to operate all electrically on current test cycles. If a lesser capability satisfies consumers and significant oil savings and environmental benefits could be realized, then regulation and legislation should be adapted to allow this to happen. DaimlerChrysler and the Electric Power Research Institute plan to evaluate intermittent engine operation accompanying electric charge depletion, which would allow electricity to replace gasoline and diesel fuel without sacrificing vehicle performance. Perhaps this type of charge depletion strategy with top all-electric speeds below 55 miles an hour would be the most attractive approach to cost-effectively achieve oil savings nationwide.

But this option cannot meet present California Air Resources Board minimum zero-emissions vehicle emissions credit requirement that vehicles operate all electrically for 10 or more consecutive miles on the federal-city test—cycle test. That test requires a top all-electric speed of 55 miles an hour.

Representative Honda had a question that my next paragraph addresses.

For decades, infrastructure will be adequate to support a far larger market penetration to plug-in hybrids than is likely. Interim reports by colleagues at three National Laboratories and Mark's work at the Electric Power Research Institute all imply that national electric infrastructure, both power plants and grid, has overnight charging capacity far in excess of plausible near-term needs.

When this eventually changes, the industry can easily and smoothly adapt. There may be some regional exceptions, but not many. Hypothetical mass success of plug-ins has been estimated by two National Labs to increase electric generation needs only a few percent and also by colleagues of Mark's at the Electric Power Research Institute.

However, it is desirable for utilities everywhere to promptly adopt overnight charging rate options for plug-ins. Automakers need and deserve this reassurance.

The problem for domestic automakers will be scarcity of resources, not resistance to plug-in research, development, and demonstration. They will want to see evidence of success in battery technology. If they see it, with rate structure encouragement from electric utilities, I believe they would develop plug-in hybrids. I believe that initial development of plug-in hybrids should focus on switching from nickel metal hydride to lithium-ion battery packs in existing and eminent full hybrids, providing 10 to 20 miles of urban electric range. Chargers should allow inexpensive plugging in using 110-volt circuits, which are standard in modern houses. Regulations or incentives requiring significantly more electric range could delay development.

The third question is how does the Federal Government support the development of plug-in hybrid electric vehicle technologies and what can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles.

The authorizations of spending and directions to include research on plug-in hybrids contained in last year's Energy Policy Act were an excellent first step. Appropriation of funds to allow the work authorized is desirable. I anticipate, as mandated plug-in studies are completed, the wisdom of a significant plug-in program will be demonstrated. Studies being promoted by the Energy Policy Act can prove very valuable by validating potential plug-in benefits. Proponents see promising implications for oil savings, greenhouse gas reductions, zero-emissions capability, energy savings, electric utility system efficiency, and emergency services. I expect careful documentation of reasons for these implications to accelerate emergence of consensus and development and deployment.

The fourth question is does the "Discussion Issues and Questions" paper in the prior DOE meeting address the most significant technical barriers to the widespread adoption of plug-in hybrid electric vehicles.

I do believe that the Department of Energy's workshop "Discussion Issues and Questions" paper and affiliated morning presentations properly identified the most significant technical and cost barriers. However, a number of excellent comments and suggestions were developed by experts there, which will lead to desirable modifications and refinements.

Question five is if a standard zero——

Chairwoman BIGGERT. Dr. Santini, if you could, sum up. I am sure we will get to those other questions.

Dr. SANTINI. Okay.

Chairwoman BIGGERT. Thank you.

Dr. SANTINI. I will move to my comments on the *Plug-In Hybrid Electric Vehicle Act of 2006*.

I provided some suggestions on wording and several instructions on plug-in grants. I like the overall content and structure of the bill. I recommend that plug-ins be allowed to qualify with less than 20 miles of all-electric range. I recommend rewording to allow flexibility in establishing the all-electric driving schedule required to qualify at the minimum range. I like the decline of per-vehicle grants over time. I suggested that per-vehicle grants in any given year be altered to create a sliding scale, increasing in magnitude with increasing all-electric range capability. I suggested much higher per-vehicle grants through about 2010 with the limit of 50 prototype vehicles per manufacturer, and then after 2010, I suggested that grants be provided to individual manufacturers only if 10,000 or more plug-ins were produced. I noticed that the funding authorization level of $200 million per year is comparable to the President's Hydrogen Fuel Initiative, but I defer to battery and electric drive experts concerning judgments on how much money is necessary.

I do understand the desire to authorize a prompt significant expansion in plug-in research, development, and demonstration, and since I believe results of ongoing studies will be quite positive, I am not inclined to ask the Subcommittee to await further study.

[The prepared statement of Dr. Santini follows:]

PREPARED STATEMENT OF DANILO J. SANTINI

Introductory remarks

Madame Chairwoman, Representative Honda, and Members of the Subcommittee, it is my pleasure to submit this written testimony in support of my more brief oral testimony concerning plug-in hybrid electric vehicles. I respond to the questions posed in your letter of invitation and provide requested discussion of a draft of the bill *"Plug-In Hybrid Electric Vehicle Act of 2006."* I believe that my comments on the discussion draft bill will be more clearly understood if they come after my responses to the questions. Note that the substance of my answers to the questions was developed before I saw the draft legislation.

1. What major research, development, and demonstration (RD&D) work remains on plug-in hybrid electric vehicle technologies? How should this work be prioritized?

In recent presentations at meetings organized by the Society of Automotive Engineers in January and May, I included very similar lists of major research needs, without providing an explicit priority ordering. However, it was not a coincidence that lithium ion battery research and development was first on the list. In my latest presentation, I listed lithium-ion battery cost, longevity, and safety as the key priorities.

Concerning the setting of priorities, I participated in the May 4–5 *Workshop on Plug-in Hybrid Electric Vehicles* at the Department of Energy. This workshop's purpose was to provide expert guidance to DOE on the priorities for the planned plug-in hybrid research program. Before that workshop a "Discussion Issues and Questions" paper was circulated to participants to stimulate discussion. I enclose that document as supporting written testimony. Although results of that workshop remain to be documented, I think the consensus view of participants was that plug-in hybrids belong in the research portfolio of the Federal Government and Department of Energy. I also anticipate that the well-chosen national and international experts will provide excellent guidance on research priorities.

I am confident enough about the potential of plug-in hybrid technology to recommend that Congress and DOE make a long-term commitment to research and development of lithium-ion battery chemistry R&D in particular, and energy storage in general, with a focus on needs of plug-in hybrids. I am also optimistic that the workshop participants will agree with my opinion that a second high priority is the conduct of a comprehensive assessment to determine where plug-in hybrid technology should be in the current RD&D portfolio of federally supported advanced 21st Century transportation powertrain and fuel options. Included in this assessment must be an examination of continuation along the present path. Costs and environmental effects of such options as oil shale, coal-to-liquids, natural-gas-to-liquids, heavy oil, deepwater oil, and arctic oil should be compared with those of improved conventional powertrains, hybrids, plug-in hybrids, and fuel cell hybrids. Ethanol and hydrogen should be evaluated as possible fuels for any of these powertrain options.

In my professional judgment "demonstration" is a very important part of RD&D. Sustained, *but steadily declining* real subsidies for critical technologies are very valuable in creating a "learning-by-doing" cost reduction path that cannot be obtained any other way. I believe that plug-in hybrids should remain on the Nation's list of critical transportation energy technologies for a long while. In effect, what government researchers think of as "demonstration" is often in reality the proper handing over of research and development to the private sector.

2. What are the largest obstacles facing the widespread commercial application of plug-in hybrid electric vehicles and what steps need to be taken to address these hurdles? (batteries, infrastructure, consumer preference, automotive inertia, cost-competitiveness, etc.)

Batteries

I quote the aforementioned white paper "battery technology could be a show-stopper for plug-in hybrids." In fact, value to the customer is the crucial hurdle. Lithium-ion batteries have swept past nickel metal hydride battery technology in consumer electronics. This could happen in hybrid vehicles, but the challenges are great. Lithium-ion is clearly superior to nickel metal hydride in terms of gravimetric and volumetric specific energy and specific power, features that have allowed the packs to be "dropped into" spaces developed for less-capable batteries and thereby enhance value to the consumer by extending operating time. "Time is money" as they say, so even though the cost per unit of energy stored ($/kWh) is presently higher for lithium-ion than nickel metal hydride, it is the runaway winner in consumer electronics. For plug-in hybrids, optimism about lithium-ion competing with nickel metal hydride batteries arises in part because the costs per unit of energy of nickel metal hydride batteries have gone up, as a result of rising materials costs. Switching battery chemistry because of increasing battery cost is not the way to build a quick mass market for hybrids, but may get potentially more attractive long-term battery chemistry into the plug-in hybrid market, which would be beneficial.

Cost-competitiveness

The fundamental battery discoveries that enabled today's hybrids were achievement of specific power and longevity far in excess of the expectations of all battery experts that we surveyed in the mid-1990s. Further, the parallel hybrid powertrain allowed effective use of much less electric energy storage for hybrids than the 1990s experts anticipated. Effective use of very small amounts of energy allowed a narrow state-of-charge swing, which allows battery life to be extended dramatically. The experts we surveyed had anticipated a series hybrid powertrain that would cost more than an electric vehicle. Instead, the technology commercialized by the Japanese that succeeded was a parallel hybrid powertrain that costs far less than a comparable electric vehicle, and also costs less than a series hybrid. This commercial hybrid succeeds economically in part because there is no attempt to make the electric drive suitable for all-electric operation serving universal customer needs.

Consumer acceptance

Therein are problems limiting consumer acceptance of the plug-in hybrid. Adaptation of current parallel hybrids will not allow consumers to drive all-electrically with performance suitable for universal use. The need to fully deplete batteries should reduce battery life relative to conventional hybrids. Top all-electric operations speeds would not match required current urban and highway test speeds. There are multiple ways to deal with these limitations, too numerous to mention here. All will add cost, but if adopted successfully could add significant consumer value and marketability to a plug-in hybrid concept.

Nevertheless, a key question is whether we should ever expect or require a plug-in hybrid to operate all-electrically on our current test cycles. It may be far more cost effective to recognize that we cannot afford this capability and develop new test cycles legitimate for a totally new kind of vehicle. Test cycles are, after all, a reflection of the behavior of the technology being tested. If a combination of attributes of plug-in hybrids can be found that makes consumers more satisfied, then regulations and legislation should be adapted to allow this satisfaction to be realized.

In the short-run, DaimlerChrysler is not attempting to make its plug-in hybrid Sprinter serve all needs when operating all-electrically. Selection of the plug-in option by customers using all-electric operation in slow stop-and-go driving may create a profitable niche market.

An alternative battery charge depletion strategy

DaimlerChrysler and the Electric Power Research Institute also plan to evaluate intermittent electric operation with charge depletion, which would allow electricity to replace gasoline or diesel fuel use without sacrifice in vehicle performance. But this option cannot be guaranteed to provide the extremely low emissions that California Air Resources Board (CARB) regulators originally hoped for when creating its first emissions credit system for plug-in hybrids required to operate continuously in all-electric mode for 20 miles or more. Note that CARB has since modified the credit system to allow plug-in hybrids with 10 miles of all-electric range on the city test cycle to obtain credits. A sliding scale of increasing credits as range increases remains in CARB's plug-in credit system. I recommend a sliding scale of grants increasing with range in the draft legislation.

For the Nation as a whole, where all-electric operation may seldom be needed for air quality purposes (many hybrids are already among the cleanest light duty vehicles), charge depletion with intermittent engine operation might be the most attractive approach to consumers. Such hybrids would still have to have emissions as low as for conventional vehicles. Charge depletion with intermittent engine operation could be implemented in places and at times when emissions would be low enough to cause no air quality deterioration.

Infrastructure

Infrastructure is adequate to support a far larger market penetration of plug-in hybrids than is likely to be seen for decades. Interim reports from ongoing analyses by colleagues at Argonne National Laboratory, the National Renewable Energy Laboratory, Pacific Northwest National Laboratory and the Electric Power Research are all highly supportive of the argument that the electric infrastructure—both power plants and grid—is adequate on a national average basis to serve any plausible plug-in hybrid market for many years. There are likely some regional exceptions, but not many. Avoiding charging at times when the grid is at peak load is important, but I am confident that creative minds will readily determine how to avoid charging at critical times and places. I am also confident that such restrictions will prove quantitatively paltry relative to annual hours of charging and operation of plug in hybrids and to total national electricity generation.

To enable any automakers to take advantage of the capability of our infrastructure we need to develop economically legitimate model off-peak incentive rate structures and encourage utilities and Public Utilities Commissions across the Nation to adopt such rates. This is a critical path item that should be done as rapidly as possible; to assure automakers that the national power generation and distribution industry does support the introduction of plug-in hybrids. Commitment to retention of the rate structures for a long period is highly desirable.

Automotive inertia

In my opinion, under the current fuel price environment, and given the level of political as well as geological uncertainty about availability of oil supplies, automotive inertia is no longer the primary problem constraining the development of plug-in hybrids. Time and scarce resources are now a problem. For U.S. motor vehicle manufacturers, the traditional preference of consumers for large vehicles means that a shift in oil and gasoline prices has a larger effect on U.S. producers than on vehicle manufacturers in competing nations. Losses of market share for large domestically produced vehicles occur at the same time that investment in production of more fuel efficient technology becomes increasingly desirable to U.S. consumers. This puts U.S. producers in a bind with respect to profitability and capability to develop new technology, even if they are willing.

Because of limited resources, it seems less likely that U.S. automakers will be less likely to develop a plug-in hybrid in new purpose-built platforms such as the Prius. Instead, if trying to get a plug-in hybrid vehicle to market promptly, they would be likely to try to adapt the coming full hybrid powertrains and a vehicle containing them. DaimlerChrysler is adapting an existing vehicle platform's powertrain its plug-in Sprinter program. Adapting existing vehicle models implies limitations on battery space and all-electric range that could be provided. One recent paper study by Siemens implied that a lithium ion battery pack option in place of a nickel metal hydride pack could lead to a hybrid with between 10 and 20 miles of all-electric range, which is comparable to the expectations for the plug-in Sprinter. Such a capability would be consistent with adoption of cheap 120V overnight charging, with little or no modification of the wiring in most modern houses, at least for the first plug-in hybrid in the household. Promotional information on a SAAB hybrid show-vehicle indicated that if a breakthrough in lithium-ion batteries were achieved in the next few years, their vehicle could use such a battery and operate all-electrically at speeds up to about 30 mph and travel 6-12 miles in all-electric mode under those conditions.

These are the kinds of plug-in hybrids that I would expect to initially emerge in the market. They may not pass the current California Air Resources Board's test to allow plug-in hybrid emissions credits, but they could offer many consumers in the United States the opportunity to decide whether they would like to have a capability to save gasoline by using electricity and perhaps drive to nearby destinations all-electrically.

Consistent with my professional judgment that demonstration in market niches is a critical path step to widespread market success for a technology, I am encouraged by the possibility that such plug-in hybrids produced by original equipment automakers will emerge within a few years. An obstacle would be for the government to try to alter this evolutionary path and push the industry to develop plug-in hybrids with so much range and/or all-electric operations capability that major redesigns of vehicle platforms would be required to accommodate large enough battery packs to comply, and/or powerful enough electric motors.

3. How does the Federal Government support the development of plug-in hybrid electric vehicle technologies? What can the Federal Government do to accelerate the development and deployment of plug-in hybrid electric vehicles?

The authorizations related to research on plug-in hybrids contained in the *Energy Policy Act of 2005* (EPACT05) are an excellent first step. Funds should be allocated to allow the work. Although I may be premature in saying this, since I'm a scientist committed to the value of peer review, I do believe that as mandated studies of plug-in hybrids called for in Section 705 are completed, the wisdom of focusing on plug-in hybrid vehicles will be strongly supported.

In trying to prepare summaries of ongoing activities by the Federal Government and private sector for the recent meeting at DOE, I have been very encouraged by the response to EPACT05. From my perspective as an analyst EPACT05 appears to have caused a shift in thinking and priorities among the many key parties that must work cooperatively to make plug-in hybrids succeed. I have found the recent dialogue very valuable, in that it answers a lot of my questions and strengthens my opinion that this technology deserves a high priority in a portfolio of options to ensure that U.S. consumers continue to enjoy a high level of transportation services in the 21st Century, with far less environmental damage.

I believe that the studies that EPACT05 is promoting can be very valuable by illustrating the potential benefits of plug-in technology. In the white paper we mentioned that the enthusiasm for plug-in hybrids that caused the legislation in EPACT05 arises from promising implications for oil savings, greenhouse gas reductions, timely and well placed zero emissions capability, energy savings, improvement in electric utility system efficiency, and provision of emergency services. In my opinion, comprehensive confirmation and testing of existing and emerging estimates, with thorough peer review, will reassure the public, electric utilities, automakers, government employees, elected representatives and the scientific community that there is significant merit to steady, deliberate pursuit of success for this technology. Although the process is often slow, I have always been optimistic that careful technology assessment can result in the most desirable technologies, and eliminate those that lack merit.

Thus, I believe that Congress should allow RD&D to proceed for a while and then review the plug-in hybrid RD&D programs for a more detailed needs assessment, in light of the evolution of events (and battery technology) over the next few years.

I am concerned about EPACT05 Sec. 706 (b) (2). Requiring a minimum of 250 miles per gallon of petroleum consumption to provide funding for plug-in hybrid demonstrations could cause adversely affect RD&D. In my view, for near-term technology, the only way to meet this requirement would be for the plug-in hybrid to also be able to run primarily on ethanol, probably as E–85.

Emissions with charge depletion and intermittent engine operation may involve difficulties for current hybrid emissions control systems running on gasoline, much less E–85. Our experience with flex-fuel gasoline/ethanol vehicles whose emissions control system was originally designed for gasoline was that when adapted for E–85 they generally had higher emissions running on E–85 than on gasoline. Thus, forcing plug-in hybrids to simultaneously develop an ability to use both electricity and E–85 might create a major "show slowing" impediment to implementation, requiring far more costly emissions control and implementation delays. I would emphasize that a plug-in hybrid is a multi-fuel vehicle, even if it does not have the ability to run the engine on an alternative fuel. Further, for many years hence the E–85 fueling capability of conventional powertrain flex-fuel vehicles already in and entering the market will greatly exceed the quantities of E–85 available. Thus the EPACT Section 705 (b) (2) requirement satisfies no useful near-term commercialization need. In my opinion, this requirement should be repealed. I am pleased to see that this requirement does not carry over into the present draft of the *Plug-In Hybrid Electric Vehicle Act of 2006.*

4. Does the "Discussion Issues and Questions" paper address the most significant technical barriers to the widespread adoption of plug-in hybrid electric vehicles?

I believe that the "Discussion Issues and Questions" paper and the affiliated morning presentations did properly address the most significant technical and cost barriers, identified opportunities, and educated participants concerning important considerations outside their field of expertise. However, the reasons for the workshop were to assure that we had not missed anything, confirm that our best judgment was legitimate, and help set priorities among items on our list. Based on my recollection of the reports of the breakout sessions on May 5, the discussion paper did set the stage well, but a number of excellent comments and suggestions were developed by the experts, which will lead to desirable modifications and refinements.

5. If a standard ZEV range was needed to facilitate the commercial application of PHEVs, what would be the optimal ZEV range that would still allow users to meet their driving needs? What would be the likely impact on fuel economy and oil savings?

One point made at the DOE meeting is that there is no single ZEV range that will suit all consumers. The ideal range will vary by consumer, depending upon driving patterns. According to the Electric Power Research Institute's 2001 study *Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options,* consumers with relatively short commutes would always prefer a plug-in hybrid with a relatively short all-electric range, while consumers that had a long commute became more interested in plug-in hybrids with a lot of all-electric range as the theoretical cost of the plug-in powertrains came down. Since batteries will probably always be relatively expensive, it will always be smart to only purchase as much electric range as you can use in everyday travel. So, just as consumers have a choice of engines in most vehicle models, the participants thought that consumers should be given options in battery size and electric range capability. In one trade-off analysis by scientists at the National Renewable Energy Laboratory, if a single range were picked, a range between 10 and 20 miles seemed most likely to be cost-effective to the largest number of consumers. If the range of the plug-in hybrid were 20 miles, then those who only needed 10 miles might not benefit. However, of those being able to use perhaps 15 miles or more, all were estimated to benefit from a plug-in hybrid with 20 miles of all-electric range.

Effects of plug-in hybrids on oil savings will depend dramatically on future oil prices and on regulatory priorities with regard to all-electric operation. Although the vehicles have so far been evaluated under the assumption of one or less charges per day, this perspective is too narrow. Possibly a more important question is what is the plausible range of electricity substitution for gasoline in the event of a range of gasoline prices? What is the degree of resilience of our economy that would be provided by the flexibility of consumers owning plug-in hybrids to shift from less than one charge per day to more than two per day? Could such an increase in charging frequency be accomplished with battery life remaining proportional to total energy throughput?

Oil Savings

The total national benefits depend on two interacting factors—how many vehicles can be sold, and once they are sold, how much oil each vehicle can save (a variable quantity, as discussed in the prior paragraph). While plug-in hybrids with a lot of all-electric range could save more oil per vehicle than plug-in hybrids with only a small amount of electric range, we don't know if enough of the vehicles with a lot of range would be sold. The short term risks to the automobile industry of "jumping" to plug-in hybrids with a lot of all-electric range instead of making less-challenging adaptations of existing powertrains has not been evaluated in prior studies, but this would also be a factor to consider.

I believe we should start with plug-in hybrids with an "electric equivalent" range between 10 and 20 miles, try to learn to use them as cost-effectively as possible to reduce oil consumption, and hope that RD&D can lead to a steady sequence of battery improvements and cost reductions that allow platform changes to be planned in advance to take advantage of emerging battery improvements. Perhaps the number of electric range options available to customers in a single vehicle platform could thereby be expanded.

I am familiar with one idea that might nearly double the energy storage capability of a lithium-ion battery pack of a given amount of material, if successful. If such a development were to occur, we could nearly double the range of a plug-in hybrid model by simply switching to a new battery technology, with minimal adaptation of the vehicle. Admittedly, this may not happen, and it may be that the only way to extend range would be with physically larger batteries. Nevertheless, the possibility does illustrate that early emphasis on 10–20 miles of all-electric range may not be inconsistent with a long-term R&D effort whose goal is to achieve double that range.

6. How large an impact could PHEVs have in reducing oil consumption over the next 10 years?

7. How long will it take before we begin to see PHEVs in the marketplace?

The impact on oil consumption is unlikely to be large in the next decade because the plausible market share of *new* plug-in hybrids would be hard pressed to exceed one to two percent at the end of the next decade, with essentially no significant penetration early in the decade.

To help understand how long it takes for a more efficient, but significantly more costly vehicle to affect total fleet fuel consumption, consider hybrids. Hybrids, available for about a decade, have only reached a little over one percent of the *new* light duty vehicle market in 2005. At this rate, to reach one percent of the *total fleet* of cars on the road (the vehicle stock) would take nearly one more decade, at which time hybrids might reduce light duty vehicle oil consumption by about one third of one percent. Since light duty vehicle oil consumption is about half of total national oil consumption, this would be one sixth of one percent of national oil consumption.

However, since hybrids are expanding their share of the new light duty vehicle market, and since consumers drive new vehicles more miles per year, the reality will be better than this. Nevertheless, this discussion demonstrates limitations involved in turning over the vehicle stock. Successfully penetrating the new vehicle market is the first step, but it takes several years of continued success to affect the entire fleet and its oil consumption.

EPACT05 calls for plug-in hybrid commercialization within five years. If the Prius history is used as a model, the first Prius factory produced 30,000 commercial vehicles per year in 1997. The 2004 Prius comes from a new factory that can produce well over 100,000 per year. It took over five years to "mass market" sales of Prius hybrids, after the first model was commercialized. Thus, the Prius path to commercialization implies at least a decade before a tiny fraction of national oil consumption reduction could result from plug-in hybrids. The point is that the process will be slow during a peaceful, deliberate expansion of the technology.

During a true international crisis with oil supplies restricted for long periods, the contributions could be far more significant. Though subject to verification in the market, it does appear that retrofit of a Prius to become a plug-in hybrid is possible. If research promoted by EPACT05—or by private sector innovators—suggests that simple plug-in retrofits of several existing and coming hybrids would be possible, then an option would be to provide incentives for manufacturers to allow for such retrofits when they produce and sell hybrids, so that such retrofits could be accomplished in the event of a prolonged emergency, or—more optimistically—in the event of battery breakthroughs during the life of the vehicle.

Alternatively, if the plug-in option becomes "fashionable" to consumers for reasons other than just saving fuel, the technology could "take off" within the hybrid powertrain category. My opinion is that, *if* battery technology does improve enough, switching from a focus on hybrids to a focus on plug-in hybrids would be a far less daunting step than was switching from conventional powertrains to hybrids. Further, we must acknowledge that the sense of urgency about reducing oil use is greater now than in the 1990s when the Prius was developed, so the level of effort on plug-in hybrids across automobile manufacturers could be significantly greater in the next decade than for hybrids in the last.

Comments on the draft "Plug-In Hybrid Electric Vehicle Act of 2006"

While I have emphasized that a focus on lithium ion batteries is desirable, it is wise to allow administrative flexibility for energy storage research, as has been done in the legislation. This flexibility could be extended even further by deleting the word "electrochemical" in Sec. 2 (1), or substituting "electrical."

It is good that hybrid fuel cell vehicles are included. For Sec. 2 (a) (7) (A) I suggest "provides motive power by converting either liquid or gaseous fuel to power and/or uses electric power extracted from an on-board battery." I recommend this or a similar change to make it clear that a hybrid fuel cell vehicle capable of using hydrogen is included in the umbrella definition of a hybrid electric vehicle.

For Sec. 2 (a) (5) (B) I suggest "that uses a fuel cell and stored battery energy for motive power." It is fair to call this a flexible fuel vehicle because there are a number of possible original fuels from which hydrogen can be derived.

In Sec. 2 (a) (8) I suggest a bit of “word engineering” to allow the flexibility that I suggested is desirable in my prior answers to questions. Recall that CARB will now provide credit for 10 miles of all-electric range on the city cycle. If the types of plug-in hybrids I discussed are to be allowed under this bill’s research umbrella, I suggest that a lesser range and less difficult driving cycle be allowed for. I recommend that you change “20 miles under city driving conditions” to “15 miles under most urban driving conditions.” Note that average daily miles driven are about 30 miles. Based on EPRI’s preferred estimate, if a plug-in hybrid with 15 miles of range were charged once a day, gasoline use would be reduced by 31 percent. This would be equivalent to a miles per gallon increase of 45 percent.

I like the sliding subsidy scale in Sec. 2 (d). Consistent with the argument that multiple plug-in hybrid ranges should ultimately be offered to consumers, I suggest a tiered subsidy. If we think about evolution from 15 to about 40 miles of range, it is likely that one would go from congested urban driving for the 15–25 mile range, to relatively free flowing, higher speed suburban cases with 40 miles of range. I expect that, as range goes up, top electric-only speed to cover usual trips would also increase. To illustrate, for the initial $10,000 per vehicle from 2007 to 2009, one might allow $3000 for a plug-in hybrid with 15 miles of urban range, $5000 for a plug-in with 20 miles of city test cycle range, and $8500 for a plug-in with 40 miles of highway test cycle range. If any of these vehicles were flex-fuel vehicles the subsidy could be increased by $1500. This would allow an automaker to take advantage of up to $10,000 of subsidy per vehicle. If this idea were acceptable, then similar allocations could be made for remaining years.

Concerning the funding levels that are to be authorized if the draft bill becomes law, I note that if these funds were appropriated, expenditure on the plug-in program would be comparable to the President’s Hydrogen Fuel Initiative. I also note that by including fuel cell hybrids the draft bill supports the Hydrogen Fuel Initiative and may enhance the odds of success of that program. I like the fact that the funds would do “double duty” providing another path away from oil dependence via plugging into the grid, for either combustion engine or fuel cell motive power. Our ongoing R&D on pathway energy use and greenhouse gases indicates that this may be a desirable combination even if hydrogen fuel cell breakthroughs are realized. There are some pathways where generation and use of electricity for a plug-in hybrid will be a better choice than producing hydrogen for a fuel cell, whether or not the plug-in hybrid uses a fuel cell or combustion engine.

It is quite difficult when attempting to cause technological breakthroughs to know the probability of success as a function of the amount of money assigned to the task. I defer to battery and electric drive experts with respect to judgment on how much money is necessary to cause needed breakthroughs. With regard to oil prices and energy security, concerns are greater today than when the hydrogen fuel initiative started, and the circumstance of domestic automobile manufacturing is more precarious. Due to a scarcity of automaker resources and a greater national need, and due to a degree of optimism about plug-in-hybrids which started several years ago and which has increased significantly over the last several months, I am supportive of a very significant increase in funding for plug-in hybrid research, development and demonstration.

As I have stated, I believe that learning-by-doing is critical, so I support the grants provision.

It is possible that the allocation of funds might be better tilted toward production subsidies. $50,000,000 per year, if allocated at $10,000 per plug-in hybrid, would support only 5000 vehicles. On the other hand, if $3000 were to be adequate to create an incentive for a 15 mile hybrid suitable to run electrically for most urban driving, then one manufacturer’s production run of about 17,000 vehicles could garner the present draft’s total subsidy for each vehicle produced. Most factories produce hundreds of thousands of vehicles, while the initial Prius factory produced 30,000 per year. So, if the intention is to cause multiple factories to produce plug-in hybrid powertrains, the incentives may not stretch far enough. One positive feature of incentives of this nature is that the government only has to pay them if vehicles are produced. If production capabilities with economies of scale are an intended outcome, I would suggest after 2010 that no manufacturer be allowed any subsidy unless a minimum of 10,000 plug-in hybrid powertrains were produced and sold per year. Total subsidies, which may need to be larger, could be allocated among all manufacturers meeting this criterion.

The first steps toward mass production of plug-in hybrids are likely to involve limited runs of prototype vehicles. In its Sprinter program, DaimlerChrysler intends to follow a sequence from less than five vehicles to 30, then hopefully large fleet tests, and finally commercialization. This process was anticipated to take four years. Thus, it might be desirable to alter the subsidy authorization schedule to allow for significantly higher per vehicle subsidies in the first four years for prototype vehicles produced in the dozens. You might consider subsidies as high as $100,000 per vehicle, up to a total of 50 vehicles per manufacturer from about 2007 to 2010. Thereafter, impose the 10,000 unit production volume requirement and a per vehicle maximum grant schedule similar to the present one for any further subsidy. This would be consistent with the Energy Policy Act goal of commercialization within five years.

BIOGRAPHY FOR DANILO J. SANTINI

Senior Economist, Section Leader, Technology Analysis, Center for Transportation Research, Argonne National Laboratory

Danilo Santini obtained his Ph.D. in Urban Systems Engineering and Policy Analysis from Northwestern University in 1976, a Master's in Business and Economics from the Illinois Institute of Technology in 1972, and a Bachelor of Architecture from MIT in 1968. From 1968 to 1970 he taught Physics and Math at George Washington High School in the Kanawha County school district in West Virginia. He worked at three Architectural firms over the period 1963–72. He began working at Argonne National Laboratory in 1974. Dr. Santini was Chair of the Chicago Chapter of the International Association of Energy Economists from 1985–86. From 1992–2004 Dr. Santini was section leader of the Technology Assessments section within the Center for Transportation Research at Argonne National Laboratory, and now is leader of the Technology Analysis section. He served as Chair of the Alternative Fuels Committee of the National Research Council's Transportation Research Board from 1996–2002. In 2003 he was awarded the title Senior Economist. Since May of 2001, he has been the Department of Energy's primary technical representative for the U.S. to the International Energy Agency Implementing Agreement on Hybrid and Electric Vehicles. In 2003 he became a member of the American Transportation Research Institute's Research Advisory Committee. Dr. Santini has authored, co-authored or edited 150 articles, reports, and conference papers.

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May 15, 2006

Representative Judy Biggert
Chairwoman, Energy Subcommittee
House Committee on Science
Suite 2320, Rayburn House Office Building
Washington, DC 20515-6301

Dear Representative Biggert:

This is to provide a record of financial disclosure according to the Rules of the House of Representatives for testimony at your Subcommittee on Energy Hearing titled, "Plug-in Hybrid Electric Vehicles: Legislation to Promote Research and Development," on May 17, 2006.

I am supported by Argonne National Laboratory under a Management and Operating Contract (No. W3-109-ENG-38) between the U.S. Department of Energy and the University of Chicago.

During fiscal year 2006, a total of $960,000 worth of research projects have been assigned directly to me for management and supervision of participating scientists and contractors. These funds are directly assigned to me from the Office of Freedom Car and Vehicle Technologies (OFCVT) of the U.S. Department of Energy. I may also indirectly receive and be assigned management responsibility for as much as $650,000 during this fiscal year, from OFCVT funds distributed within Argonne under Dr. Larry Johnson's management. Ultimate totals will depend upon funding allocation needs and priorities of OFCVT management. As much as $600,000 of these funds is for research related to plug-in hybrids.

Please let me know if you require any further information.

Sincerely,

Danilo J. Santini, Senior Economist
Section Leader, Technology Analysis
Center for Transportation Research

DJS/dmn

DISCUSSION

Chairwoman BIGGERT. I thought we were going to have technical difficulties.

Thank you very much.

And now, at this point, we will open our round of—first round of questions.

And I recognize myself for five minutes.

My first question is that the legislation that we are considering has two major components. One is the research on batteries, the control systems, and the lightweight materials, and the second is a demonstration component that would add federal dollars to efforts to purchase plug-in hybrid vehicles. And right now, the research—right now, the ratio is $5 of research for every dollar of demonstration. Is this the right ratio and why? If anyone would like to start, take a stab on that.

Mr. Duncan, you look like——

Mr. DUNCAN. Thank you.

I cannot say exactly whether it should be five-to-one or whatever. The people who are more technical and the research and development area can speak to that. I am just happy to see that the $50 million dedicated to demonstration vehicles because that is certainly—there is an overwhelming demand among the people who learn about plug-in hybrids to have some vehicles spread around the Nation. Right now, we have a couple of vehicles in California and some in New York and one in Kansas and trying to move those vehicles around the Nation to meet the demand of people who want to see one and drive one is tremendous. So we—I am very happy that we are providing some money. And I think the important thing is to get a number of vehicles in various states all at once. And I do not know if the five-to-one ratio is appropriate, but——

Chairwoman BIGGERT. Okay. Thank you.

Anybody have any information on that?

Dr. Frank.

Dr. FRANK. I would like to say that, you know, the plug-in hybrid is—uses components developed by the hybrid cars, and so we are going just one step further. And while there are still things that have to be researched, of course, as pointed out by Mr. German at Honda, but really, I think, at this point, we should be spending more in demos and less in R&D, because this is near-term technology , and it is not something like the hydrogen program. So I would like to see the ratio closer to two-to-one.

Chairwoman BIGGERT. Thank you.

Let me just follow up with that, then.

There seems to be some disagreement about how—just how far along these technologies are. And I think Dr. Frank and Dr. Duvall indicate that they are quite close to the market. And Mr. German, you seem to cite numerous difficulties. I think that you talk about the heating and longevity as the main issues with the batteries and—what has been the experience with batteries in transportation use, and why do you think these are disagreements? And then I think, Mr. German, you talked about storage, too, and also mentioned that—what are we going to do with these batteries when they wear out? And actually, if we have to replace them within, you know, 90,000 miles, is this—how much of a cost is that going to be?

Mr. GERMAN. Yeah, the—I think that our hesitation to launch immediately into demonstration fleets has to do with the previous demonstration program in California on battery electric vehicles, which was hugely expensive and did not succeed in advancing battery technology to the point where it could be commercial for battery electric vehicles. And what we are concerned is the same thing may be happening here is that the—you need a good battery, or a good source of energy storage of some kind in the system. And it is critical that we do the R&D on this, and this what we like about the House proposal. But there is no question that these plug-in batteries are going to be subjected to more severe operating conditions. They are not going to last as long. And they are very expensive. I haven't even talked about the current price, because that is just prohibitive. You know. We are trying to estimate where the price might be with further development, and there is a lot of uncertainty there, but even that price is potentially a problem with customer acceptance.

Chairwoman BIGGERT. Thank you.

Anybody else like to comment? Dr. Duvall, I think that you had a different point of view.

Dr. DUVALL. Well, I would present a different point of view, and that is that our experience has led us to believe that the current state-of-the-art for automotive batteries, particularly with lithium-ion, shows extremely good use—durability in this application. We are not ready to say that they are ready for production, but they are certainly ready to move to the next stage, which is to be run in very rigorous, real-world demonstration programs and a certain number of them. When we started working on the battery electric vehicles, the first vehicles launched with very primitive, very short-lived batteries in the mid-1990s, but by the end of the decade, so before 2000, some of the best vehicles in class were tested by certain utilities up to 150,000 miles of battery life under extremely rigorous conditions with extremely hot weather charging. So the technology showed that it could dramatically improve year over year very quickly.

And the same thing is happening now with lithium-ion batteries. There is a lot of activity. There are some startling innovations going on right now that show tremendous potential to improve the technology. And it is important to understand that a plug-in hybrid vehicle really relies on its battery, and the better that battery is, the more electric capability the vehicle has, the more range, the more petroleum you can displace.

So to really state right now, we believe the best batteries are very good and good enough to really be run through their paces and attempt to really understand how long they can last. It is a different operating cycle than a hybrid, but I think it is unfair to say that it is directly more severe or less severe. It is different. That needs to be understood.

Chairwoman BIGGERT. Thank you.

My time has expired.

Mr. Green from Texas, you are recognized.

Mr. GREEN. Thank you, Madame Chairlady.

And I would like to thank our Chairman and Ranking Member for having this hearing. I think the intelligence that we are acquiring is invaluable. And I also thank the members of the panel for participating.

I attended a meeting this morning wherein our Speaker talked about the price of oil, in a sense, being a blessing in disguise. By going up to the extent that it has, it has caused us to focus on these various alternatives. But then he went on to make another comment, and that is that there are people in the world who are capable of manipulating the price of oil such that if we start to make an inordinate amount of progress, the price of oil can be brought back down. Now whether that is true or not is debatable.

But first, I ask how important has the price of oil, the escalating of the price of oil, been to this process? And I see that Dr. Ricketts is prepared to answer, so why don't you take the first stab at it. I read faces quite well.

Dr. RICKETTS. Thank you.

Necessity is the mother of invention. My rule of thumb, it seems to be $2.50. It seems like there is not much excitement until gas gets $2.50, and then once it gets over $2.50, people start going, "Wow." Yeah, probably the best thing that could happen in this country is fuel to go to $5 a gallon and stay there for a year. We would be having committee meetings every months, we would get something done, and we will move on with it.

Mr. GREEN. No disrespect, Dr. Ricketts, it may be the best thing, but I don't—I suspect some of us might not be sitting here if it happens.

But given that high gas prices can be a benefit, sort of a blessing in disguise, what type of policies do you envision necessary to assist us such that we can make it through a crisis of $5-a-gallon oil? How would we work through that?

Dr. RICKETTS. I can't answer that question, but I was hoping you would ask me another question——

Mr. GREEN. Okay.

Dr. RICKETTS.—and that was why—that is why I am so strong about flex-fuel. If gas goes back down to $1.50, then with the flex-fuel, we will just use the gas component. But if it gets to $5 a gallon, we will use the ethanol or whatever. So that is why I am so strong on the flex-fuel part of it.

Mr. GREEN. With reference to the hydrogen that you talked about——

Dr. RICKETTS. Yes.

Mr. GREEN.—is that technology, right now, in its infancy of course, but is it something that we can assume will, at some point, replace or will it become a substitute for other technology?

Dr. RICKETTS. In my opinion, the long-term future of this country, I am talking 30-plus years, is with hydrogen and the sun, because once they are done, we won't have any need for fuel anyway. I think—I am for ethanol. I am for soy diesel. I am an agriculturalist, but I believe, at best, they have got a five- to 10-year run, because just pure agricultural economics, supply and demand, I am afraid corn and soybeans both are going to go so high that we can't even feed the country or feed our cattle for our beef and so forth. Again, that is why I like the flex-fuel. You have got so many options to go. It is almost like we are playing the stock market. Which fuel am I going to use today? Which one is the best option?

Mr. GREEN. Dr. Duvall, do you have an additional comment?

Dr. DUVALL. I think one of the keys is diversity. The—you have to have a diversity of fuels, which will allow you to address this issue, which right now is high fuel prices, or tomorrow's issue, which may be carbon management in the transportation sector, or it may be something else. And one of the key advantages to electricity, and possibly ultimately hydrogen, is that they are carriers, energy carriers, that can be generated with a number of—produces a number of different fuel sources. Also, this is one strength of biofuels. But I agree with Mr. German's statement that there is no silver bullet, that we have a very limited list of options, and we should explore all of them fully. And many of these, and especially, we believe, electricity, instantly brings you diversity and can be an instant, very secure component.

Mr. GREEN. Will the additional use of the electricity, which is generated from sources other than oil—generally speaking, about three percent of our electricity comes from oil, as I understand it. With the additional, however, tax on electricity, will we have enough of our coal, the wind, and other forms of power, nuclear, to sustain us with the plug-in cars?

Yes, Mr. Duncan?

Mr. DUNCAN. There is a short-term and a long-term answer to that. And in the short-term, the answer is an unqualified yes. The extra capacity in the electric grid, particularly at night, is—as was addressed in other testimony, is very adequate. You could put millions of these vehicles on the road without having to build a new power plant of any type.

In the long-term, however, if you are successful in transitioning a significant portion of our transportation sector over to the electric grid, you are going to have to build new power plants. And the questions remain the same, whether the plants are clean coal or nuclear or solar or wind or whatever, still have to be addressed, and in fact, in my opinion, this technology raises the stakes in those decisions. But in the short-term, there is certainly plenty of capacity for these vehicles without building new power plants.

Mr. GREEN. Thank you, Madame Chairlady.

I yield back the balance of my time.

Chairwoman BIGGERT. Thank you.

The gentleman from Michigan, Mr. Schwarz, you are recognized.

Mr. SCHWARZ. Gentlemen, I am going to ask some pie-in-the-sky questions, and you can give me pie-in-the-sky answers, if you want. But I just want to get a fix as to where we are with this technology. So just very briefly, I am going to throw these out.

How much oil are we going to save if, for example, in 10 or 15 years 10 or 15 percent of the vehicles on the road are hybrids?

Secondly, I think I am getting some fix from you on what stage this technology is in right now. You talked about the supply chain is not ready. Is there interest, real interest, from American companies, like GM and Ford? I know—and I am from Michigan, but are they serious? In your opinion, are they serious about putting hybrid vehicles on the road as opposed to ethanol-burning vehicles, E–85 compatible vehicles, that sort of thing?

And thirdly, you have got to convince me that hydrogen really is fuel X. Is there something else out there? Are your labs working on anything else? It costs money to produce hydrogen. And I am from Missouri a little bit on whether in the future it really is going to be hydrogen or not.

So I free-associated a little bit with my questions, and you certainly have my permission to free-associate with your answers—with your responses.

Thank you.

Dr. FRANK. Can I answer the first part?

I have a slide on the—that I showed. If 10 percent of the cars were plug-in hybrid, you save about 4.5 percent oil per year, which is quite a bit, actually. That is enough to make a real dent. So of course, you have got—but to get to 10 percent plug-in hybrids, it is going to take five or 10 years, because you don't replace car fleet—but—the whole car fleet—new car fleet is only 10 percent of the fleet—the total fleet. So to get to 10 percent penetration within the entire car fleet, it is a 10-year program.

So that answers that question.

Dr. SANTINI. The thing that I like about the plug-in hybrid option is that it gives us—it is part of our research portfolio that would give us a significant amount of diversity of options. And with respect to hydrogen, the bill does allow for a hydrogen plug-in option to be researched. And some of the research that we see indicates that there could be pathways, solar and wind I have in mind, in particular, would be better, and Andy Frank has pointed this out, better to simply use the electricity in the plug-in mode rather than hydrogen under those circumstances. So it would add—it may make the hydrogen option even more efficient in the very long run.

Another question on the long run, utilities, it—the paper—the presentation that I submitted into the record that was submitted at the May 4–5 workshop included analysis by the National Renewable Energy Lab and Argonne colleagues in which they evaluated the effect on the electric utility industry of massive increases of plug-in hybrids. We will be lucky if they are right, but going out to 2040 or 2050, and both of them were optimistic about wind. One of them estimated, under certain—with the higher-range vehicle, that wind could actually increase in an amount that would be sufficient to cover the needs of the vehicles themselves, the other just a share. There is reason to believe that the movement would be toward clean technology, including coal. Actually, the scenarios accelerated the development of the—an implementation of the cleaner coal technology and market-shared ways that coal can evolve in a way that it could actually reduce net CO_2 emissions. Another thing I like about the technology is that there are a number of ways that it could be seen as a benefit, and so it may have staying power if oil prices drop. I mean, it may—there may be markets where it would continue to be sold and used because of the air quality benefits. It—people might be interested because climate change is becoming more of an issue and they might buy it simply to show their commitment to that.

So those are a few thoughts.

Mr. SCHWARZ. Thank you, Madame Chair.

I see that my time has expired.

I have many questions left on this simply because, as someone who comes from an auto manufacturing state and has the biggest plant that General Motors has built in the last 50 years in my district in Delta Township, just outside of Lansing. It is imperative that we know which way this is going to go. And I don't know yet whether the hybrid is the answer, whether ethanol is the answer. The capacity of ag. to make enough ethanol and soy product comes up in my district all of the time, so I am fascinated by your answers and by the questions.

And I thank you, Madame Chair.

Chairwoman BIGGERT. Thank you.

The gentleman from Maryland, Dr. Bartlett.

Mr. BARTLETT. Thank you very much.

The observation that when gasoline went up we could then switch to ethanol for a flex-fuel vehicle, I would like to suggest that ethanol prices are very likely to track gas prices, because it is unlikely that we will do better than three-fourths of a gallon of fossil fuel to produce a gallon of ethanol. So there will be an obligatory linkage between those two.

Right now, coal provides a meaningful amount of our electricity. And the question is, would it be better to use this electricity to drive—of course, I am a big, big fan of plug-in hybrids. Or would it be more efficient simply to use the coal and produce coal oil? When I was a kid growing up, we didn't have kerosene lamps. We had coal oil lamps. I was born in 1926 and Hitler ran all of his country in World War II on coal oil, and South Africa did the same thing.

So if we simply are using fossil fuels to produce the electricity, would—all of them could be converted into a fuel to run cars. I think that if we are going to go to plug-in hybrids, don't we have to have electricity produced by other than fossil fuels or we really aren't solving a fundamental problem?

And then I have a question about how quickly we can get there. And I would like to be there tomorrow, but we have two variables here. And I know they trade off one against another. One is the price of oil. How expensive will gasoline have to be before people are serious about moving to plug-in hybrids? And secondly, how quickly can we develop batteries that are economically-acceptable? Of course, the higher gasoline prices go, the more expensive batteries can be and still be acceptable in the market. What is your best judgment as to—and I know it is anybody's guess what oil is going to do. I think it is up and up and ever up with saw teeth up and down, but more up than down. What is your best guess of how soon these two things are going to come together so that electric hybrids will be really competitive out there, that is the price of oil and improvement of batteries?

Mr. DUNCAN. Well, I will start and address the first one, and I am not really the expert on the speed of battery adaptation here. The other speakers are.

As far as using fuels other than fossil fuels, what really interested Austin in this initially is because we sell more wind power than any other utility in the Nation, and we saw a way to get wind in as a transportation fuel. And as—and the research that was addressed earlier by Dr. Santini, wind power, alone, has the capability, at least on paper, to meet this transportation need. But it—I mean, it is a fundamental decision that has to be made and as in relation to the other decisions on carbon that the Congress and the Nation need to make. I think there is no question that we have the technical capability to transition the transportation sector away from fossil fuels through the electric grid, which has the ability to take multiple fuels and combine them in any way that you want to provide a transportation fuel, if you use it that way. And it is not just the cost of gasoline itself. It is really the spread between the gasoline cost and other fuels. You mentioned how ethanol is starting to track and will track gasoline. That is not necessarily the case for the electric grid in comparison with gasoline, because you are dealing with totally different fuel structures and infrastructures. So the spread between the electric grid and the liquid fuel of gasoline and ethanol could grow to be quite great and quite rapidly.

Mr. BARTLETT. Mr. Duncan.

Yes, sir. Go ahead.

Dr. DUVALL. One of the things that EPRI forecasts for the future in the electric sector is that we have a diversity of energy sources now, and we will continue to have a diversity of energy sources in the future. And we can provide some additional information in writing to show how these scenarios play out, depending on what the future looks like. There is an aggressive technology development roadmap for coal to be more efficient, to be cleaner, and to ultimately be low-carbon-emitting at the plant level. So electricity from coal could ultimately be a very good source, very low-emitting source for transportation.

This second comment is that, in general, batteries follow a very strict cost-volume relationship. And so when there is not much production volume, the costs are very high. And when we completely learn out the manufacturing techniques for batteries and we have high consistent volume and a lot of competitive choices in the marketplace, battery costs can be minimized. It is still an expensive component. But at today's current gas prices, life cycle cost studies done at EPRI show a variety of very favorable results for hybrid and plug-in hybrid vehicles of different configurations, and we can provide examples of those in writing now. So today's fuel prices really do, I think, incentivize alternatives and more efficient vehicles.

Mr. BARTLETT. Thank you.

Madame Chairman, this is a great hearing. I wish that it occurred 10 years ago then we would still be behind the curve, actually. Thank you very much for holding the hearing. I think that plug-in hybrids are a great, great partial solution to the pending liquid fuels crisis that we are facing. And batteries are the pacing item, and any amount of money that it takes to infuse into that technology to make this happen sooner would be money well invested for our future.

Thank you very much.

Chairwoman BIGGERT. Thank you, Dr. Bartlett. And I couldn't agree more with you. I wish I had known about it 10 years ago, but since I didn't, I think that we really do have an opportunity right now to move forward with our main goal, really, which is to reduce our reliance on foreign oil, and this certainly is one means of doing that. And I think that the sooner that this can roll out, the better, as well as all of the other alternatives that we have talked about. And so I think that this is a real challenge. But we have the opportunity, and I think, as Mr. Honda had said earlier, that because of the spiraling of gasoline prices, that it calls our attention to it. What I hope, and what we can't let happen, is that we then let this slide when the gas—when the prices start going down again, as we have done so—in so many cycles before. And I think with the President's Advanced Energy Initiative and our looking at developing GNEP with the nuclear as well as the hydrogen, and I had an opportunity to drive the hydrogen car yesterday, thanks to Mr. Chairman's company. It was kind of scary to drive a $1.5 million car around the streets of Washington, but I made it without any damage, so—you know, and those things are on the way, but I think that we have to really take this very seriously and really do all that we can to—you know, to move us forward on that.

And with that, Mr. Hall, do you have a question?

Mr. HALL. Thank you, Madame.

I am—inasmuch as I have not been here, I don't know the questions that have been asked. I am honored to have Mr. Duncan here and the knowledge that he brings and the history of success that he has known and all of them to give their time, travel time, and testimony time and all. I know that the Chairlady appreciates that, as I do.

I will submit questions. I am sure you will get that unanimous consent at the end.

Chairwoman BIGGERT. Yes.

Mr. HALL. Thank you.

Chairwoman BIGGERT. Yes. Thank you.

All right. Then we will start the second round, and I will ask——

Mr. SHERMAN. Madame Chair?

Chairwoman BIGGERT. Yes.

Mr. SHERMAN. I just came into the room for the first round.

Chairwoman BIGGERT. Oh, I am sorry, Mr. Sherman.

You are recognized for five minutes.

Mr. SHERMAN. Well, I thank you.

The big problem with electric cars, whether—and the reason why we are told that we need to put a gasoline engine is their limited range. And one would hope that we would see new developments in battery technology that would solve that problem. Another way to solve that problem, and I would like your comment on it, and my guess is it doesn't work because nobody is talking about it, and it is relatively obvious, is that we could have a system where, say, the major oil companies, who happen to already have an infrastructure of service stations, would own batteries of, say, 500 pounds, you would lease those, or—from the oil companies or the service station chain owners. You would drive in. Somebody would have a forklift. Imagine service at a service station. It once happened. And they would remove your depleted 500-pound battery, install a fully charged one, both of which are the property of the same oil or other company anyway, and you would drive off for another several hundred miles. But of course, when you use the car just for commuting, you would just plug it in at your home and recharge the existing battery, but you know that the car is great for commuting, say, 48 weeks a year and that you can drive across country, if you want to, on vacation as well.

Put aside the governmental and societal problems of creating an infrastructure where there are thousands of stations across the country ready to install a battery that is fully charged and to charge—and to cause the customer to pay an appropriate amount, and deal with the technical problems of a battery-switching electric—a nationwide system of battery-switching electric cars, knowing that most of the time they are going to be recharged by the consumer, but on cross-country trips or whatever, or you just happen to have a lot of driving, you can stop at a service station.

Mr. DUNCAN. Congressman, two responses.

The first is that that is why we were so excited about the plug-in hybrid is that it did not have the range limitation of the all-electric vehicle. It is truly a hybrid. If you don't plug it in or forget to plug it in, it still goes. So we didn't have the range limitation and it didn't require a special charging station. You could put it into an ordinary wall socket to charge it.

As far as the second suggestion, I think it is a good suggestion, and actually, it is my understanding that the French utility EDF has the type of system that you are talking about where you can drive in and they will exchange a battery in your vehicle.

Mr. SHERMAN. How much would a—using current or technology pretty well guaranteed to be available in the next couple of years, how much would a battery weigh that could get you 200 or 300 miles?

Mr. DUNCAN. I don't know the answer to that.

Dr. DUVALL. I think Mr. German and I can agree that it would weigh—it would still be a lot. I think maybe the more critical——

Mr. SHERMAN. Excuse me. Can you—a lot is not the kind of specificity we are used to in the Science Committee.

Dr. DUVALL. Okay. It would be a minimum of a 50- to 60-kilowatt hour battery, which would probably weigh somewhere around 300 to 600 kilograms, depending on how good the battery was. I think the major——

Mr. SHERMAN. So you are talking over—well over 600 pounds, and I put forward the idea of a 500——

Dr. DUVALL. The more critical aspect would be the battery would be extremely expensive, and the architecture of a modern car is extremely complex and may not facilitate the installation. But it requires a lot of volume and a lot of packaging design work to integrate that battery into a vehicle and to integrate it to be easily removable. This is done very common—this is very common for electric material handling equipment. Forklifts with electric batteries are—often have the batteries changed so that you can run a two- or three-shift operation where you don't have time to stop the vehicles and charge. But actually, high-power fast charging is becoming an alternative even there, because there is a certain amount of time that if you actually did, maybe, the back of the envelope economics, that the labor required to change the batteries and the added cost, it might not work out as well.

Mr. SHERMAN. With high-power recharging, how long would it take to recharge an automobile with a 200-mile range?

Dr. DUVALL. Twenty to thirty kilowatts of charge capacity is pretty common, and there are—is a possibility to make that greater in the future.

Mr. SHERMAN. All right. Then I want to say how long would it take, using the technology available two or three years from now.

Dr. DUVALL. An hour to two hours to completely recharge a battery with significant range capable and, like, a five- to 10-minute recharge.

Dr. RICKETTS. Mr. Sherman, I will tell you how far we have come with better technology. I am still using deep cycle lead acid. I have 26 batteries on my truck at 70 pounds a piece. That is 1,820 pounds of batteries. That will get you just 60 miles. So these fellows with the lithium-ion, that is how far we have come.

Mr. GERMAN. But you need to consider the interior space in a vehicle is extremely valuable.

Mr. SHERMAN. But let me just ask one more question. The Chair has been very indulgent with time. And that is, let us say I just use the car for short range, so I am always home to plug it in. And I never actually turn on the gasoline engine. And let us say I happen to live in one of those very few American cities where they actually generate the electricity using petroleum. And so you have to burn a certain amount of petroleum to get a certain amount of kilowatts to charge my commuter car. How many miles per gallon or—am I getting? In other words, how much fuel do you have to burn at my local electric utility, assuming it is burning petroleum, and I realize most don't, but some do, in order to get me 100 miles or whatever the range is?

Dr. DUVALL. It would almost certainly be lower than if you——

Mr. SHERMAN. I know, but is it three times lower, 10 times lower, or 20 times lower?

Dr. DUVALL. No, it would be a fraction lower. I can provide an answer later, but it would be some fraction lower. It wouldn't be double the fuel consumption. In most areas where there are still oil-fired power plants, they are primarily peaking plants, and so they only operate a very limited number of hours per year. So in general, the margin of electricity, wherever you are in the United States, is probably not petroleum unless there is some peak activity.

Mr. SHERMAN. I yield back.

Chairwoman BIGGERT. Thank you.

We will start a second round, if we could go quickly, and I have just a couple of questions.

Going back to the battery, some experts suggest that the lithium-ion batteries are the answer for the plug-in hybrid vehicles yet this battery type has been under development for many years and still presents challenges for use in the vehicles. So I would like just a quick answer from Dr. Frank and Dr. Duvall and Mr. Duncan and Mr. German. What is your view on the lithium-ion batteries? Just a very, very brief——

Dr. FRANK. Real quick, you—batteries for all of these cars are no longer benign things. They are all intelligent batteries with computer controls. And by the way, computer control is a very small marginal cost for the total battery system. The computer controlled batteries are what will make lithium even metal hydride now practical for these kinds of applications. And it changes the picture entirely. So it becomes very practical very quickly.

Chairwoman BIGGERT. Thank you.

Mr. Duncan.

Mr. DUNCAN. I will defer to the other witnesses on the battery question. I am not——

Chairwoman BIGGERT. Okay.

Mr. DUNCAN.—the expert in this field.

Chairwoman BIGGERT. Okay.

Dr. Duvall.

Dr. DUVALL. I would like to share an opinion of a representative of one of the leading auto makers with respect to hybrid vehicle technologies who felt that we would see lithium-ion batteries introduced into commercial hybrid vehicles within three years and by 10 years, likely to dominate the market. So there—I think there is a strong undercurrent that believes that the technology is rapidly becoming ready for automotive application. And there are already at least one or two commercial applications of lithium-ion batteries in commercial hybrid vehicles.

Chairwoman BIGGERT. Thank you.

Mr. German.

Mr. GERMAN. I think part of the problem here is that when people say lithium-ion, they have the connotation that you have a single battery. And the—part of the problem I had with lithium-ion is that the formulations, depending on anode materials and other things are tremendously variable. And what the industry has been—batteries have been doing is experimenting with all of these different combinations trying to come up with something that has both high energy and good durability and is robust and long-lasting. And it is very difficult. They are still working through this. As far as the lithium-ion batteries for conventional hybrids, that is actually a different formulation than you need for a plug-in. Plug-ins need to be lower power density, higher energy density. So even those might not be the optimum for plug-in. It is this complexity that is causing the problems, and they are still trying to find the right combination.

Chairwoman BIGGERT. Okay. Can you estimate if it will be cost-effective?

Mr. GERMAN. It depends on how you define cost-effective. The estimate—the targets I have seen for lithium-ion batteries, even in the future in high volume, are not going to be accepted by most customers. Certainly there can—might—may be a niche market. But it is very difficult to talk about the future price of lithium-ion because we don't know what the pace of development is going to be. That is why research and development is so important.

Chairwoman BIGGERT. Dr. Santini.

Dr. SANTINI. Lithium-ion has eclipsed nickel metal hydride in consumer electronics and at the advanced automotive battery conference last year, there was a presentation that indicated that a very large number of patents of lithium-ion batteries had been adopted by Nissan, Toyota, and Honda, not by the battery manufacturers. So obviously, the auto industry found the technology to be intriguing. So that is indirect evidence that it is a promising technology. John gave you a very good description of the difficulties and the fact that it is very complex, many alternatives. There is an alternative that my colleagues at Argonne have that they are hopeful would double the amount of energy storage per unit volume and per unit—per kilogram. If that would happen, that would be a great boom. So——

Chairwoman BIGGERT. Well, I have been out to see your program at Argonne. You are doing a great job.

And then just one other question. This really isn't—part of this—it is really not the jurisdiction of the Science Committee, because it has to do with tax relief and tax credits, but the hybrid cars right now, and under the energy bill that we passed in—last August, has a component in for tax credits for buying hybrid cars. And the companies are limited to 60,000 cars sold a year. And it—a question is, of course I think probably we would have to have something like that for hybrid plug-ins to have that, because what people tell me when they go to buy a hybrid is that they are so expensive that the tax breaks makes it—brings it down to about equal to a regular car. But they are also—they can't get them, that there is such a waiting list. And I see this happening, you know. I am certain—since I already want a plug-in, I am sure everybody else does, too, and it is going to be hard to get them, but—and I think that Dr. Santini, you, in your testimony, said about 100,000 of the hybrid cars like the Prius had been sold, in the past year, it started out, you know——

Dr. SANTINI. Per year.

Chairwoman BIGGERT. Per year. Right. Is that holding up for most all of the hybrids? The SUVs and——

Dr. SANTINI. We—sales showed some sensitivity to oil prices over the period—it looked like, anyway, from the Katrina, and then prices subsided. The sales came down a bit. And then, you know, when, more recently, the prices have spiked, and sales—the pressures took off. Toyota said that the Prius—there was actually a decline in Prius' monthly sales rate, but Toyota said it was due to availability and some glitches——

Chairwoman BIGGERT. But why aren't these companies, then, making more of them when they are—you know, they are wanted by the public? Is there some reason why there is such a backlog when other—you know, other—the regular cars? Is it cost? Or does anybody know?

Dr. SANTINI. Well, one thing I am—that I observed in studying the purchasers and the highest level of interest in hybrids was that high level of education explained it much better than annual driving, for example. So there are people that, I think, are probably a relatively significant market that are interested in the technology for many of its, sort of, own sake attributes.

Chairwoman BIGGERT. So we probably need an education or a PR campaign as well about the benefits and the conservation that people would be making by driving these cars?

Dr. SANTINI. That is why I think that the ongoing study is trying to cover all of the potential benefits look—that look promising for their ability to back up leaders.

Chairwoman BIGGERT. So Mr. Duncan, with your demonstration project, is this something you think will help to—for individuals to realize the importance of conservation?

Mr. DUNCAN. Oh, absolutely. As I have said, when fleet managers and ordinary individuals are explained this technology, they have the same reaction that you and others have had: "Where do I get one?" But a major hold-up is actually being able to see and drive one and see that it drives like an ordinary vehicle does and there is nothing you have to do. So that is why I am pressing so hard to get some spread around the country instead of—I will take the vehicle you are seeing here today, in order to get it here in time, had to be flown in, because there are so few around the country right now.

Chairwoman BIGGERT. Thank you.

Mr. Sherman.

Mr. SHERMAN. Thank you.

Chairwoman BIGGERT. I am sorry.

Mr. Sherman.

Mr. SHERMAN. Okay. The electric meter at my home is 1950's technology. It cannot distinguish whether I am buying the electricity at peak or non-peak hours. If I am going to recharge a car at home, I am going to be paying, say, 10 cents a kilowatt because the—that is a fair price if you are paying, sort of , a blend between peak and non-peak fair prices. Should we have a system whereby those who own plug-in hybrids are able to fill out a form saying, "Look, this is how much electricity my car used. I only plug it in non-peak hours. Therefore, for that amount of electricity, cut me down to four cents or five cents a kilowatt." How much—this is something Congress could require. How much of an incentive will it be to getting plug-in hybrids accepted if people are able to pay a fair, non-peak cost for their kilowatts rather than having to pay the blended average rate that we all pay now?

Yes. Mr. Santini.

Dr. SANTINI. In my testimony, I mentioned that it is very important for the electric utility industry across the country to adopt, and I—in the written testimony, I used the word economically-legitimate off-peak rates as promptly as possible and show the auto industry that what they tell me and what I believe as an economist that there are good reasons for low marginal costs off peak. And I—it is a short-term benefit to the—not short-term, but it is a significant benefit to the electric utility industry, so the rates should be in place. Now whether Congress should require that or not, I didn't say that, but——

Mr. SHERMAN. Well, it would need, almost, a consumer-completed form. There—at a huge industrial facility, they can keep track of how many kilowatts are on-peak and how many are off-peak and how many—and at my home, there is no way to know when—which kilowatts are going to the TV I am watching during peak hours and which kilowatts are being used in—to recharge the car. But if you had a system by which, perhaps under penalty of perjury, the same way you sign a tax form, you are able to inform the utility how many recharge hours you used, and they were required to give you the same low rate that they give non-peak industrial customers, that would be a reduction in price. I am trying to get a handle on this from a consumer standpoint. I know what it costs to operate a regular car. I know what it costs to operate a hybrid car. And I know that a plug-in hybrid is going to be somewhere in between a purely electric car on the one hand and a hybrid non-plug-in car on the other. Let us say I buy one of these plug-in hybrids and I never have to turn on the electric—the gasoline motor, because I just use it for short distances. What is my fuel or energy cost per mile at 10 cents a kilowatt? How many miles can I go per kilowatt if I am just going short distances.

Dr. FRANK. Well, these cars have—I can answer that. Or maybe I can answer part of that. But these cars get about 250 watt hours per mile, roughly.

Mr. SHERMAN. Two hundred and fifty watt hours——

Dr. FRANK. Watt hours per mile.

Mr. SHERMAN.—per mile. And at 10 cents a kilowatt, is——

Dr. FRANK. Well, there are two-tenths of a—0.2—a quarter of a kilowatt hour a mile.

Mr. SHERMAN. A quarter of a kilowatt hour, so I am paying 2.5 cents to go a mile——

Dr. FRANK. Yeah.

Mr. SHERMAN.—for fuel costs?

Dr. FRANK. Right. That is about right. Yeah.

Mr. SHERMAN. Whereas, at $3 a gallon, even if I am getting 30 miles per gallon——

Dr. FRANK. It is about 12 cents kilowatt——

Dr. SANTINI. The EPRI study had about 0.3 kilowatt hours per mile, and my colleagues are concerned about effects of air conditioning and auxiliary loads, so I use 0.38 in some of my most recent calculations. I am going to give you a range of values to think about.

Mr. SHERMAN. Okay. So I am seeing one range here of a difference between 2.5 cents a mile and 12 cents a mile?

Dr. FRANK. That is about right.

Mr. SHERMAN. That is about right?

Dr. FRANK. Right.

Mr. SHERMAN. Okay. And that is at—that is paying the regular cost for electricity rather than non-peak cost?

Dr. FRANK. Right. Right.

Mr. SHERMAN. So that could come down——

Dr. FRANK. Even more than that.

Mr. SHERMAN. Okay. The other problem I——

Mr. GERMAN. Keep in mind that even if you drive, I am sorry, 800 miles a month just on the battery alone, that is going to work out to $20 a month on your electric bill. Getting this low rate is going to cut it from $20 to $10. And I am not sure how much of an impact it is going to have on the customers.

Mr. SHERMAN. Got you. So what you are saying is that the technology—the fuel usage economy is already so good——

Dr. FRANK. Yeah.

Mr. SHERMAN.—that you don't need to pay a fair price for the electricity? The other thing that is missing, of course, is places to plug it in.

Dr. FRANK. That is an incentive right there to plug it in.

Mr. SHERMAN. Well, no, what I mean—what we have not done, as a society, is require every garage owner to have places you could plug it in, whether it be three or whether it be—or whether you would, you know, be coin-operated or whatever, the most important thing that would make my vehicle more efficient is drive to work, have a place to plug it in——

Dr. FRANK. Yeah.

Mr. SHERMAN.—and then use the electricity to come back rather than having to use the engine. I hope that as the bill goes forward, we are able to come up with a workable plan to require those in the business of garaging cars to provide a few spots where you could re-plug.

Dr. FRANK. In Canada, they do, you know. Canada has—the cold climates have plugs on every parking spot.

Mr. SHERMAN. I wonder if Mr. Duncan has a comment, and then my time is expired.

Mr. DUNCAN. Speaking from an electric utility, I think you are right on target with several points. Several—the electric utility could start providing—charging positions in parking garages. Ultimately, you know, you could even reverse this technology, and if we started wiring parking garages, a vehicle could charge at night, come in, plug in, and then on a hot afternoon day in Austin, for instance, we could actually reverse that charge and draw down just a little bit on a whole bunch of batteries and avoid peaking power plants. The transportation system could actually act as a capacitor in that regard. The utilities could certainly start to offer off-peak pricing during the evenings for charging. I think that you may find one of the greatest obstacles in the electric utility industry is not really the technology of the metering and such but the billing system. And it has been my practical limitations on learning how to—in dealing with this. But it is certainly all possible within the electric utility industry.

Chairwoman BIGGERT. Thank you.

Before I recognize Ms. Jackson Lee, I just wanted to remind everyone that is here that we do have the demonstration out at New Jersey and C Southeast, which is right out—just a block away. And I think that I will enjoy seeing the hybrid plug-in cars that are available there. So I would urge you all to—after here to go over there.

So now, Ms. Jackson Lee from Texas, you are recognized.

Ms. JACKSON LEE. Thank you very much, Madame Chair. Thank you for, I think, a very timely hearing.

Let me welcome Mr. Roger Duncan from Austin, Texas. We are just—or at least Austin Energy in Texas. And hopefully—is that in Austin?

Mr. DUNCAN. Yes, ma'am.

Ms. JACKSON LEE. And we are your neighbors in Houston. So let me welcome you and congratulate you for some of this work.

Thank you for yielding to me, and I ask for you to indulge the fact that I was in a Homeland Security hearing, but I thought this was extremely important. I am going to raise, just, some questions, and I would like everyone to take a stab at them.

Obviously, you are in the backdrop of the rising eye of Americans on gasoline prices and the lack of focus on alternative fuels. And so I raise the question on, first, though you may have covered this, the kind of standards necessary to begin to set up the framework of an industry that would engage in the plug-in hybrid. I would also be interested in what role universities can play in this research. Are we at the peak level of the research, or can we utilize new technologies through more research funding through universities? I am also concerned about the workforce. This is a broad question of alternative fuels, but the plug-in is particularly unique. What skills will the new—or training will the new workforce need to really, if you will, plug in to this new plug-in hybrid to make this a viable industry or a viable concept? And finally, the Administration has the Advanced Energy Initiative. Is that enough, or what more can we do? I am noting legislation that is proposed to this committee, and I am going to be looking at this very carefully. But what more can we do around the Advanced Energy Initiative to really pump, if you will, energy into this concept of alternative and this plug-in hybrid?

And gentlemen.

Dr. SANTINI. Well, I will speak first.

The—I am proud to have been associated with the—but very indirectly, just—most of my colleagues did the work, the student competitions program that Andy mentioned earlier where a number of technologies have been evaluated over the years, but this is a cooperative program of universities, industry, and the National Labs that has tried to work to make it—to keep it moving and with a good topic every year. So but the plug-in hybrid technology itself emerged, in part, as a result of the student competitions. It did train students to work in the auto industry. So I think it is a good model going forward. It has been focused on very long-term technology. We may be in a different environment, but it is a good model, and working with universities has—is probably responsible for the great interest, in significant part, in plug-in hybrids now.

Ms. JACKSON LEE. And should—we should expand that work with universities?

Dr. SANTINI. Well, you certainly—if the technology is to succeed and if electric drive is a technology that is a great long-term interest to the country, and I believe it looks like it is, then probably it should—something like that should be expanded.

Ms. JACKSON LEE. Thank you.

Just jump in.

Dr. RICKETTS. I feel strong about demonstration projects. My, probably, role in this energy thing is more a linker in linking these technologies together. Earlier, I explained the processes in producing hydrogen. I didn't really invent any of that, but I brought the electrolysis unit together. I brought the solar unit together. I brought the storage together. So it is there in a demonstration spot so that people could come in and see how it can be done.

Ms. JACKSON LEE. Others? The training, the standards, the amount of money invested?

Dr. Frank.

Dr. FRANK. Yeah, I really would like to say that one of the biggest problems we have in judging these hybrids, and especially plug-in hybrids, which uses, really, two energy sources, electricity and gasoline, is how to measure performance. EPA has, over the years, established performance for conventional cars. That is miles per gallon and emissions and so on. But no standards, no such standards have been made for a dual fuel—dual energy source system like the plug-in hybrid. And we have to establish those standards so that industry can have something to work towards. And it is—that is kind of the first step that we should be taking, establishing those kinds of standards to give all of the car companies an equal footing on getting a program started.

Then your last point was on advanced energy?

Ms. JACKSON LEE. The Advanced Energy Initiative that has been proposed by the President. Is it enough? Or what more do we need to do?

Dr. FRANK. Yeah, I think the—that—in that program, you number of—you specify a number of areas where you are going to be putting money into. And relative to the plug-in hybrid, I think the plug-in hybrid has the biggest chance to offset the use of oil. And we really should be focusing on that now, because this is an important—this is the most important thing for our country. So I would like to see a reallocation of resources and effort on—in that energy bill. Some of the things that are important are, perhaps—lightweight materials is important, but that is a much longer research. And certainly fuel cells may be, but that is even longer research. So what is important now to the country is to do something that we can get started now on.

I mentioned earlier, even if we were to start the plug-in program today, we would only be saving about five percent of the oil after five or six years, and maybe even 10 years. So all of these other programs, it would be—it is even longer than that. We have got to do something in the next five or 10 years.

Mr. GERMAN. Yeah, the—your basic research on batteries and other forms of energy storage is extremely important, not only for plug-in hybrids but for conventional hybrids, for battery electric vehicles. There are neighborhood electric vehicles that are already a commercial market, and there are ways to expand that. Even fuel cells can benefit from it. So I think that anything you—any amount you can spend on basic energy storage research is going to be money well spent.

Ms. JACKSON LEE. Mr. German——

Chairwoman BIGGERT. If we could close this, we are—there are—we are expected at the demonstration of the hybrid cars that have——

Mr. SHERMAN. Request 20 seconds.

Chairwoman BIGGERT. Go ahead.

Ms. JACKSON LEE. If I could let someone just tell me about the skills, and I will end. And I thank you, Madame Chairwoman. I will just—if someone just have skills, and I will certainly thank you for any other answers you can put in writing. I thank you.

Mr. German.

Dr. DUVALL. Duvall, actually. I think that——

Ms. JACKSON LEE. Dr. Duvall, I am sorry.

Dr. DUVALL.—one of the main requirements that is needed in the university are now that we are putting a lot of power electronics on board vehicles and high-voltage systems is that power systems engineering has become extremely rare at the university level. It is a common concern in the utility industry before transportation. A lot of the electrical engineering students cannot—simply cannot study power systems engineering even though they go to major research universities. And I think this is one extremely important near-term requirement, because the—we will have to be training engineers and technicians that are very familiar with power electronics and power systems.

Ms. JACKSON LEE. Thank you. Thank you very much.

Chairwoman BIGGERT. And with that——

Mr. SHERMAN. Madame Chair, if I could just speak for 20 seconds.

Perhaps your slogan, or our slogan, should be "Plug in to 62-cent-a-gallon gasoline," because I have done the calculations.

Dr. FRANK. Yes.

Mr. SHERMAN. And 2.5 cents a mile is like taking us back to 62 cents a gallon.

Dr. FRANK. Right.

Chairwoman BIGGERT. Before we bring this hearing to a close, I want to thank our panelists for testifying before the Energy Subcommittee.

If there is no objection, the record will remain open for additional statements from the Members and for answers to any follow-up questions the Subcommittee may ask the panelists. Without objection, so ordered.

This hearing is now adjourned.

[Whereupon, at 12:06 p.m., the Subcommittee was adjourned.]

Appendix 1:

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Mark S. Duvall, Technology Development Manager, Electric Transportation & Specialty Vehicles, Science & Technology Division, Electric Power Research Institute (EPRI)

Questions submitted by Representative Michael M. Honda

Q1. Do you see the development of advanced plug-in hybrid vehicles more as a transitional technology to get us to the point where fuel cells are available or as a substitute for fuel cells for transportation purposes?

A1. They are separate and complementary technologies. The role of electricity in transportation is to introduce an energy source that is extremely efficient, can be generated with many low- or non-emitting (including renewable) plant technologies, and is relatively near-term in its commercialization prospects. The role of hydrogen fuel cells is to replace combustion engines—increasing efficiency and allowing the use of non-petroleum, renewable energy sources (although at lower efficiency than direct electricity-battery systems.

As an example, hydrogen is a very good fuel for large, commercial applications like trucks, transit buses, and other vehicles that use a very large quantity of diesel fuel each day. These vehicles are fueled at large depots, minimizing hydrogen infrastructure requirements and there are significant criteria pollutant savings by replacing the diesel engine with a hydrogen fuel cell.

For light- and medium-duty vehicles, a plug-in hybrid with 20–40 miles of electric range will generally have superior fuel cycle energy use and greenhouse gas emissions compared to an equivalent fuel cell vehicle, with dramatically lower infrastructure costs.

Hydrogen vehicles are unlikely to become either as efficient or as cost-effective as plug-in hybrids in the foreseeable future. Renewable electricity (e.g., wind) is three to four times more efficient when applied to a plug-in hybrid or electric vehicle as when used to generate hydrogen.

In the future, these two technologies will likely co-exist and can even be combined as plug-in hybrid fuel cell vehicles—the fuel cell replaced the combustion engine and the vehicle runs on a combination of electricity and hydrogen energy.

Q2. In your statement, you say that the most recent batteries demonstrate excellent safety, power performance, and laboratory life. Future challenges will include verifying lifetime testing, and developing production facilities to ramp up the availability of this technology. Expand on your statement and tell us what you see as the biggest hurdles in the development of satisfactory batteries and why these problems continue to be significant.

A2. The single most important issue with advanced batteries for plug-in hybrid vehicles is that there is presently no large-scale manufacturing capacity for these batteries. Existing lithium ion "energy" batteries are adequate to meet the near-term requirements of plug-in hybrids. The costs of these batteries are currently high because volume is very low. The government and industry need to discuss how to "prime" this market so that battery suppliers will build the manufacturing capacity to supply an emerging plug-in hybrid market. This can provide promising opportunities to incentivize domestic manufacturing capacity.

We currently need to do more testing (both in the laboratory and in the field with demonstration vehicles) to thoroughly understand how to get the best long-term performance from plug-in hybrid battery systems. Near-term R&D needs to focus on large-scale demonstration programs (minimum of 200–300 vehicles) as this will promote both good battery system development and provide suppliers and manufacturers with valuable in-use data on the performance of these systems.

A secondary issue is to encourage and support R&D on new energy batteries suitable for plug-in hybrids. The majority of the battery R&D in transportation is focused on high-power designs for current hybrid vehicles. Specifically supporting R&D on high-energy designs more suitable for plug-in hybrids will help promote further development to ensure that energy batteries continue to improve in cost, performance, and durability.

Q3. You mention in your testimony that one of the three technical challenges is the development of a set of charging standards. Of the three parties you mention—government, the auto industry and the electric utilities—which one should take the lead in developing the standards? Should the legislation address the standards issue, and if so, what should be done?

A3. The utility industry should take the lead on this issue, but charging standards must be developed in tandem by the automotive industry and utility industry to account for both vehicle-related and infrastructure-related aspects of standardization. The utility industry already has an organization in place—the Infrastructure Working Council (IWC)—to facilitate this collaboration between industries. The IWC has worked in the past to bring auto manufacturers, utilities, and component suppliers together to develop standards and make appropriate recommendations to the official standards-making bodies like SAE, NEC, etc. The Federal Government, who already participates in the IWC (via the National Labs), can support this process both technically and financially. Legislation can direct the DOE to support the standards making process.

Questions submitted by Representative Eddie Bernice Johnson

Q1. The President has requested $12 million for R&D on plug-in hybrids, including an increase of $6 million for R&D to develop better car-batteries.

Is this amount enough to provide sufficient momentum for development and application of these technologies? What amount do you feel is sufficient for such an initiative?

A1. There are three previous federal programs that were similar in intent and objectives-the U.S. Advanced Battery Consortium to develop electric vehicle batteries, the FreedomCAR (PNGV) effort to develop hybrid electric vehicle technology, and the FreedomCAR program to develop hydrogen and fuel cell technology.

Ramping up plug-in hybrid vehicle program support to similar levels as these programs will significantly aid commercialization prospects for the technology—the technology gaps for plug-in hybrids are significantly fewer than for each of the previous programs at their inception.

ANSWERS TO POST-HEARING QUESTIONS

Responses by John German, Manager, Environmental and Energy Analyses, American Honda Motor Company

Questions submitted by Representative Michael M. Honda

Q1. Do you see the development of advanced plug-in hybrid vehicles more as a transitional technology to get us to the point where fuel cells are available or as a substitute for fuel cells for transportation purposes?

A1. It is not possible to give a definitive answer to this question. Clearly, at some point in the future transportation must become truly sustainable, with no net carbon emissions and little, if any, fossil fuel use. There are a number of possible options that could provide this sustainability. One broad option is a fuel cell vehicle powered by hydrogen created from renewable sources. Another possibility is battery-electric vehicles powered by electricity created from renewable sources. A third option could be highly efficient vehicles powered by fuels created with renewable methods, such as biomass and waste-to-energy. Combinations of these three broad options are also possible.

To further complicate matters, there is a multitude of potential pathways forward that could greatly improve our energy security and reduce greenhouse gas emissions while we are working towards truly sustainable technologies. Also note that from a technical and market viewpoint liquid fuels have two huge advantages, assuming similar production costs and environmental impacts. One is a readily available infrastructure with very fast, convenient refueling. More importantly, liquid fuels have very high energy density. Ten gallons of gasoline only weighs 62 pounds, but contains about 330,000 Wh (watt-hour) of energy. By comparison, a current state of the art NiMH battery (70 Wh/kg) with the same energy capacity would weigh over five tons. A theoretical advanced Li-ion battery pack (120 Wh/kg) would still weigh over three tons. One of the advantages of fuel cells over battery electric vehicles is that hydrogen energy density is a lot better than battery energy density. However, hydrogen is a very lightweight gas that is difficult to compress and turns to liquid only at -423°F (-253°C). Thus, the energy density of hydrogen is still much worse than liquid fuels.

As long as fossil fuels are readily available, battery-electric and, to a lesser degree, hydrogen vehicles need a breakthrough in energy storage in order to compete with liquid fuels in light-duty vehicles. This is the appeal of hybrid vehicles, as they obtain large improvements in efficiency with relatively small battery packs. This is also where plug-in hybrid vehicles may be able to compete if the cost of energy storage comes down, as liquid fuels are still used to provide extended range when needed. However, note that the current electrical grid has a large coal fraction with high CO_2 emissions, especially for the marginal units that would be used for transportation. A switch to plug-in hybrid vehicles would not help reduce global warming gases very much unless electricity generation moves to low greenhouse gas sources.

If hydrogen storage is resistant to solutions or the cost of making and distributing hydrogen proves to be higher than other options, then highly efficient conventional vehicles, possibility including hybrids and plug-in hybrids, may be the optimal solution for a long time. But there are a lot of potentially productive pathways that may not include either of these two alternatives. For example:

- Efficient hybrids (not necessarily plug-in) could lead to fuel cell vehicles.
- Efficient ICE vehicles utilizing renewable liquid or gaseous fuels could lead directly to fuel cell vehicles.
- Natural gas and hydrogen ICE vehicles could lead to fuel cell vehicles and hydrogen.
- If a genuine breakthrough occurs in energy storage, then hybrid vehicles and plug-in hybrid vehicles are more likely to be a transitional technology to battery-electric vehicles, or a mixture of fuel cell and battery-electric vehicles.

Questions submitted by Representative Eddie Bernice Johnson

Q1. The President has requested $12 million for R&D on plug-in hybrids, including an increase of $6 million for R&D to develop better car batteries.

Is this amount enough to provide sufficient momentum for development and application of these technologies? What amount do you feel is sufficient for such an initiative?

A1. Honda strongly supports R&D to develop better energy storage in general. Better energy storage is critically needed for hybrid vehicles, plug-in hybrid vehicles, and battery-electric vehicles. Improved energy storage, including both batteries and ultra-capacitors, will have great benefits for all types of hybrid and electric vehicles. Fuel cell vehicles may potentially benefit as well.

Batteries have been in widespread use and development for over 100 years. If it were easy to develop an improved battery, it would have already happened. Advanced battery formulations are extremely complex and there are a wide variety of options that need to be explored. While $6 million for R&D to develop better batteries is not likely to be enough, it is not possible to predict the pace of technology development. Larger amounts of research increase the chances of finding a breakthrough and battery research should be among Congress' highest energy-related R&D priorities. Congress should seek a five-year research plan from the Department of Energy that is updated annually to reflect progress. Funding should be reevaluated as the plan is updated.

ANSWERS TO POST-HEARING QUESTIONS

Responses by S. Clifford Ricketts, Professor, Agricultural Education, School of Agribusiness and Agriscience, Middle Tennessee State University

Questions submitted by Representative Michael M. Honda

Q1. Do you see the development of advanced plug-in hybrid vehicles more as a transitional technology to get us to the point where fuel cells are available or as a substitute for fuel cells for transportation purposes?

A1. I did not believe that the development of advanced plug-in hybrid vehicle is either (1) "a transitional technology to get us to the point where fuel cells are available" or (2) "a substitute for fuel cells for transportation purposes."

Rationale for Statement (1): I did not believe "plug-ins" are a transition to anything. I believe that they are viable within themselves. It is unfathomable that the automotive companies ever built hybrid vehicles without the plug-in component (option). Fuel cells are the power for the future for automobiles, but presently they cost 6.5 times the equivalent horsepower of an internal combustion engine. Furthermore, plug-ins cost one-third as much as gasoline per mile.

Rationale for Statement (2): Plug-ins are not a substitute for fuel cells. Plug-ins are valuable today, and offer many opportunities to run vehicles off a variety of energy sources through the grid lines. As mentioned above, fuel cells are the power source in vehicles for the future, but due to the cost the future is twenty to thirty years away.

My Proposal for the Future: In reality, I don't believe *"The Plug-In hybrid Electric Vehicle Act of 2006"* goes far enough. CalCars and others have already developed plug-in hybrids. Let us amend the Act and call it "The Flex-Fuel Plug-In Electric Vehicle Act of 2006." Let us get real serious about the energy crisis. I have always been taught not to bring up a problem unless you have a solution. The following is where I really believe our legislation should center:

(1) Provide research funds for researchers (public or private) to develop *flex-fuel vehicles to run off (a) plug-in (b) gasoline (c) ethanol (d) hydrogen (e) propane and (f) natural gas.* Note: These vehicles exist but are not available as plug in hybrids.

Justification: With the plug-in component, we have the infrastructure to run vehicles off nuclear, solar, wind, hydro, plus the fossil fuels. Gasoline is still an option, ethanol can be used in places where it is available. Hydrogen can be used where it is available, and be used as a transition in the internal combustion engine until fuel cells are feasible. Propane and natural gas could be used in the same vehicle if they are more economical. Really, this is a "no-brainer." That is, let us develop a flex-fuel plug-in hybrid spark-ignited vehicle that will run off anything that the spark-ignited (gasoline) vehicle can run off individually.

(2) Provide research funds for researchers (public or private) to develop a *plug-in flex-fuel spark-ignited (gasoline)/heat of combustion (diesel) engine.* For example, a six or eight cylinder engine could be developed that uses three or four cylinders as spark-ignited and three or four cylinders as heat of combustion.

Justification: This vehicle could run off everything in proposal one just discussed, plus the engine/vehicle could run off diesel, soybean oil, and other vegetable oils. This would be the ultimate alternative fuel vehicle that could run off anything. This vehicle would be the true bridge (transition) until fuel cells are available.

Questions submitted by Representative Eddie Bernice Johnson

Q1. The President has requested $12 million for R&D on plug-in hybrids, including an increase of $6 million for R&D to develop better car-batteries.

Is this amount enough to provide sufficient momentum for development and application of these technologies? What amount do you feel is sufficient for such an initiative?

A1. I don't fell qualified to answer this question. However, I am very passionate about the answer to Representative Honda's question. The only educated response that I can give to the question is that a researcher at a National Energy Convention from Zebra Battery said that they could develop a battery for any range if they had enough orders to justify the research, set-up, and construction costs. Therefore, I believe the technology is available, it is just a matter of cost-efficient ratio, and I do not know what that is.

ANSWERS TO POST-HEARING QUESTIONS

Responses by Danilo J. Santini, Senior Economist, Energy Systems Division, Center for Transportation Research, Argonne National Laboratory

Questions submitted by Representative Michael M. Honda

Q1. Do you see the development of advanced plug-in hybrid vehicles more as a transitional technology to get us to the point where fuel cells are available or as a substitute for fuel cells for transportation purposes?

A1. Actually, though it is only an educated guess at this point, the answer is neither. I speculate that R&D on the two technologies will lead to a shift of focus of fuel cell vehicle development toward a plug-in hybrid fuel cell vehicle. If that is correct, then the development of plug-in hybrid vehicles would be complementary to, and enabling of fuel cell vehicle technology.

Imagine a success scenario where plug-in hybrids with initially limited range and electric use capability evolve to plug-in hybrids with conventional engines and 30 to 60 miles of all-electric range, followed by plug-in hybrid fuel cell vehicles with similar all electric range. In my view, this could take one to two decades to evolve. With such a capability, on most days within an urban area, consumers could use electricity. Since far less hydrogen would need to be delivered within the urban area, this would reduce hydrogen infrastructure construction needs. Since the costs of hydrogen delivery infrastructure are high in urban areas, this cost is an impediment to hydrogen fuel cell vehicles. Also, if fewer hydrogen delivery stations had to be built within urban areas, fewer suitable sites would need to be found, probably making safety issues less of a problem.

Also, even with less electric use capability than for a plug-in hybrid with 30–60 miles of electric range, a plug in infrastructure in place could allow electric heating of fuel cell stacks of plug-in fuel cell vehicles prior to unplugging. This could help to greatly reduce concerns over delays while awaiting fuel cell stack warm-up. Further, since a fuel cell stack in a plug-in hybrid could be smaller, there would be less stack mass to keep warm.

Finally, if half of a plug-in fuel cell vehicle's mileage was provided via grid electricity, this would mean that the total hours of use of the fuel cell stack could be half as much as in a grid independent fuel cell vehicle with the same total mileage. Since stack life (total hours of service) is an issue of concern, this could allow fuel cell stacks to be successfully introduced sooner, with more reliability than would otherwise be the case.

Though all of these theoretical opportunities would need to be examined carefully, they are each arguments that support the possibility that plug-in hybrids could make fuel cell power units more quickly available, at a lower total cost to the customer.

A reason that it would likely be desirable to keep the plug-in option as a part of the fuel cell powertrain is that the battery storage of electricity from wind power and solar energy would provide more miles of travel than if that electricity were used to produce hydrogen by electrolysis and used to power the fuel cell stack. Conversely, once fuel feedstocks were gasified to separate carbon and hydrogen, it would be less efficient to use the hydrogen to produce electricity for the grid for use in the plug-in battery than to use hydrogen on-board to power the fuel cell stack.

From another perspective, previously produced hydrogen should be used in the fuel cell stack to generate electricity on board a vehicle rather than to generate electricity off-board for use in electric vehicles. The reason is that the energy storage capability of the hydrogen fuel cell powertrain is far better than for batteries—even lithium based batteries. Thus, if urban areas of the future desire a zero tailpipe emissions vehicle (as several presently do), but customers continue to desire a vehicle with 300 or more miles of range, a pure battery electric option cannot meet the latter need, while a hydrogen fuel cell vehicle can.

The enticing feature of a hydrogen fuel cell stack is that its electric generation efficiency is not particularly sensitive to scale. For other methods of generating electricity, if the amount of power generated is as small as the amount required to power a vehicle, the efficiency drops sharply. But for a fuel cell stack, a very small stack with a power rating suitable for a vehicle will be about as efficient as a stack providing megawatts of power, and will be far more efficient than an internal combustion engine.

In my view, opinions of some colleagues notwithstanding, along with battery cost, the inability of electric vehicles to provide customers driving range comparable to gasoline vehicles has been their Achilles heel. Until and unless we know that a battery electric vehicle can accomplish such a feat, it is appropriate to conduct research on fuel cell vehicles. Though lithium based batteries would get us closer to a range capability acceptable to the consumer, at the present time my estimates imply that they still could not provide enough range at an acceptable cost. A related issue is the amount of material and processing energy required to provide large enough batteries to provide the needed vehicle range. Note that a 2001 MIT study (On the Road in 2020) estimated that a theoretical nickel metal hydride battery electric vehicle with 300 miles of range would cause more greenhouse gas emissions than a hybrid electric vehicle with 470 miles of range, due to processing energy in battery production. This has to be looked into for li-ion, but you see that it is an issue. While GM says that it now has a prototype fuel cell vehicle (the Sequel) that can achieve 300 miles of range, I am not aware of any manufacturer claiming that there is or soon will be an electric vehicle which can do this.

Remember that one of the attractive features of both electric vehicles and fuel cell vehicles, from environmentalist's point of view, is that they can never fail to provide zero tailpipe emissions, even if they are not functioning properly. Many regulators and environmental scientists I have worked with have been concerned with what are called "gross emitters"—vehicles whose emissions control system has failed. Plug-in hybrids using internal combustion engines are unlikely to ever be perfect in this regard. So, assured zero tailpipe emissions capability will likely remain a reason that many members of the environmental community will maintain an interest in the fuel cell vehicle. Thus, this is another reason to maintain research on fuel cell vehicles.

Q2. How can the organized research community tap the creativity and talents of the experimentalists who push technologies and open our eyes to the possibilities of technological breakthroughs?

A2. In my opinion, the U.S. private sector is the most vibrant and productive in the world in tapping creativity of experimentalists. Further, much of the organized research community wishes to tap into the riches that can become available if a technology is successfully pursued, so experimentalists do get the best opportunities in the world here.

I believe that the one area where innovators—those who bring a product to market—would be well served by the research community would be through far more unbiased, independent testing and verification of results claimed by experimentalists. Testing and verification is of value to both experimentalists and technology innovators because it helps more efficiently allocate resources. When the claims of the experimentalist are shown to be unwarranted, the mode of failure or area of weakness of the technology is identified, allowing the experimentalist to focus any further work on weak points. Should the claims of the experimentalists be verified, then innovators such as venture capitalists can more confidently invest in the conversion of the experimental technology to a market ready technology.

Actually, I believe that verification and testing—under real conditions that the product will experience in the hands of consumers—is extremely important if we want to successfully accelerate the adoption of advanced vehicle technologies. If we don't do thorough testing and become knowledgeable about technology limitations before the technology is in the hands of consumers, then early versions of the technologies will be seen to be failures. Such experiences could delay—or even worse eliminate—a technology that could save the Nation a lot of oil if used properly, recognizing its strengths and weaknesses. This may mean spending considerable amounts of money to develop new test facilities and methods. A simple contemporary example is the approved methods of testing of vehicles with "auxiliary loads"—air conditioning in particular—turned off. Vehicles are also tested and officially rated—across the world—as if they were driven far less aggressively than in actual use by consumers. For hybrid vehicles these omissions led to expectations and claims of greater percentage improvements in fuel economy than has actually been realized "on-road" by consumers. As a result, the Environmental Protection Agency has been working on the development of a significantly more costly set of vehicle tests than used in the past—adding low and high temperature tests and more "aggressive" and higher top speed driving tests. The plug-in hybrid will be a far greater challenge than even the hybrid, which itself has caused us to rethink our vehicle testing protocols. To develop reliable new technology plug-in hybrid batteries suitable to consumers throughout the U.S., we will need a lot more testing at extreme environmental conditions. We should plan on constructing facilities and establishing multiple fleet test locations that will allow us to do such testing. With regard to the need to expand the testing "envelope," testing over a wider range of speeds and acceleration/deceleration conditions will be necessary. Legal speed limits have moved up since existing test protocols were developed, and the increased power available in vehicles allows more rapid acceleration. Texas just moved the maximum rural speed limit up to 80 mph.

In my opinion, both hybrids and plug-in hybrids will provide owners an ability to manipulate their fuel efficiency to a far greater degree than for a conventional vehicle, by altering their driving behavior. If so, I would argue that potential consumers would need to be made aware of this. Driver education might eventually be adapted to provide training in how to get the best fuel economy out of hybrids and plug-in hybrids.

The bottom line is that if we want to see experiments work their way successfully and expeditiously into the market, the technology being experimented with needs to be tested thoroughly and realistically. In my view, both rigorous field tests and much better laboratory tests need to be supported.

Q3. There is a belief that there is a secondary market for current generation of lead acid and nickel metal hydride batteries after they are retired from service in hybrid vehicles. Do the characteristics of Lithium-ion batteries lend themselves to follow-on uses after being used in vehicles?

A3. At this time, I would not regard myself as an expert on secondary markets. The most appropriate answer would be "I don't know," or "it remains to be determined."

As you imply, although batteries used in hybrids may end their useful life from the point of view of suitability for the vehicle customer, they may have remaining useful life from the point of other customers. Power and/or energy per unit mass and volume may no longer suit the hybrid vehicle owner, but may be adequate for other purposes. For nickel metal hydride hybrid batteries, I believe that it remains to be seen whether a significant post-vehicle market for used batteries will develop, other than the recycling market.

Of course recycling is presently the primary source of residual value. The secondary market for recycled materials has proven to be important to date for lead acid and nickel metal hydride at the end of their useful life for all purposes. Others have speculated that recycling of lithium ion batteries is less likely than for nickel metal hydride. However, for hybrid batteries in particular, I suggest that this would be subject to the yet-to-be determined path of battery development, and should be affected by battery design and pack design. Many combinations of materials and assembly configurations are being considered, so it is too early to do anything more than study the possibility of development of secondary markets and recycling probability. My understanding is that the Department of Energy Office of FreedomCAR and Vehicle Technologies Energy Storage Program now requires assessment of recycling in each of its contracts supporting development of different battery chemistries and designs. Perhaps investigation of possible secondary markets should be included as well.

My limited knowledge is that there is one secondary market for used vehicle batteries in less developed nations that do not have rural grid electricity. For these locations, use of batteries, charged at a not-too distant small generating facility, provides television, radio and perhaps computer services. For such markets, the batteries have to be carried back and forth between the generator and the customer. Since li-ion has more kWh of energy storage per unit volume and per unit mass than lead acid batteries and nickel metal hydride batteries, it would have an advantage in this market. More kWh of battery capacity could be carried in existing transport equipment. Similarly, more kWh of capacity could theoretically be loaded onto a ship for transport from the U.S. to other nations.

However, one of the issues to be resolved with li-ion is shelf life (years of life, regardless of rate of use), and another is the possibility of fire due to overheating and venting of flammable gases in the event of excessive overcharging. Both of these factors would work against li-ion relative to nickel metal hydride or lead acid.

Q4. Should there be a more systematic role for the Federal Government in developing standards for the various elements of plug-in hybrid vehicles and its associated infrastructure or should these activities be left to the private sector?

A4. I have just submitted a draft paper to an academic journal which addresses the role of technical standards in the U.S. as a part of the process of causing a transition from one transportation technology to another. The argument of that paper is that technical standards, adopted or codified by government in response to pressure from industry and the public, have always played a critical role in such transitions. I studied transitions through the 1800s and 1900s. In view of the arguments of that paper, I would say that it would be without historical precedent for the U.S. to leave the introduction of the plug-in hybrid vehicle to the private sector. Even if it tried to do so, segments of industry would at some point lay one or more sets of technical standards on the table and ask government to make them official.

Typically, the process of developing standards involves years of back and forth discussions between industry and government(s), with both groups responding to or trying to manipulate public opinion. It will be no different in this case. Testing and demonstration is a typical part of this process. Expect it to be necessary again. I do think that the process can be more systematic. My earlier argument for support of more thorough and realistic testing is intended to make the process work better and faster than it otherwise would, hopefully leading to earlier and more appropriate technical standards than would otherwise be the case.

I would say that the process of developing and implementing technical standards is actually already very systematic and built into how the capitalist system works within the context of our government structure. The form of your question—how to make it "more" systematic—was apt.

Questions submitted by Representative Eddie Bernice Johnson

Q1. The President has requested $12 million for R&D on plug-in hybrids, including an increase of $6 million for R&D to develop better car-batteries.

Is this amount enough to provide sufficient momentum for development and application of these technologies? What amount do you feel is sufficient for such an initiative?

A1. The President in his budget submission must make judgment on many worthy programs. I am in no position to offer a better judgment given the myriad of programs. When it comes to specifying an amount that will provide a predictable outcome for advanced R&D to cause a technology to succeed, no one, even in the technical community, is able to provide a precise answer. But I believe it is safe to assume that if Congress and the President determine that greater financial resources are warranted, they would be effectively utilized and a greater chance of success is probable.

Appendix 2:

Additional Material for the Record

[DISCUSSION DRAFT]

MAY 16, 2006

109TH CONGRESS
2D SESSION

H. R. ____

To reduce the Nation's dependence on foreign sources of oil by promoting plug-in hybrid electric vehicles and related advanced vehicle technologies.

IN THE HOUSE OF REPRESENTATIVES

M__. __________ introduced the following bill; which was referred to the Committee on ______________________

A BILL

To reduce the Nation's dependence on foreign sources of oil by promoting plug-in hybrid electric vehicles and related advanced vehicle technologies.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Plug-In Hybrid Electric Vehicle Act of 2006".

SEC. 2. NEAR-TERM VEHICLE TECHNOLOGY PROGRAM.

(a) DEFINITIONS.—In this section:

(1) BATTERY.—The term ''battery'' means a device or system for the electrochemical storage of energy.

(2) BIOMASS.—The term ''biomass'' has meaning given the term in section 932 of the Energy Policy Act of 2005 (42 U.S.C. 16232).

(3) E85.—The term ''E85'' means a fuel blend containing 85 percent ethanol and 15 percent gasoline by volume.

(4) ELECTRIC DRIVE TRANSPORTATION TECHNOLOGY.—The term ''electric drive transportation technology'' means—

(A) vehicles that use an electric motor for all or part of their motive power and that may or may not use offboard electricity, including battery electric vehicles, fuel cell vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, flexible fuel plug-in hybrid electric vehicles, and electric rail; and

(B) related equipment, including electric equipment necessary to recharge a plug-in hybrid electric vehicle.

(5) FLEXIBLE FUEL PLUG-IN HYBRID ELECTRIC VEHICLE.—The term ''flexible fuel plug-in hy-

brid electric vehicle'' means a plug-in hybrid electric vehicle—

(A) warranted by its manufacturer as capable of operating on any combination of gasoline or E85 for its onboard internal combustion or heat engine; or

(B) that uses a fuel cell for battery charging when disconnected from offboard power sources.

(6) FUEL CELL VEHICLE.—The term ''fuel cell vehicle'' means an onroad vehicle that uses a fuel cell (as defined in section 803 of the Energy Policy Act of 2005 (42 U.S.C. 16152)).

(7) HYBRID ELECTRIC VEHICLE.—The term ''hybrid electric vehicle'' means an onroad vehicle that—

(A) can operate on either liquid combustible fuel or electric power provided by an onboard battery; and

(B) utilizes regenerative power capture technology to recover energy expended in braking the vehicle for use in recharging the battery.

(8) PLUG-IN HYBRID ELECTRIC VEHICLE.—The term ''plug-in hybrid electric vehicle'' means a hy-

brid electric vehicle that can operate solely on electric power for a minimum of 20 miles under city driving conditions, and that is capable of recharging its battery from an offboard electricity source.

(9) SECRETARY.—The term "Secretary" means the Secretary of Energy.

(b) PROGRAM.—The Secretary shall conduct a program of research, development, demonstration, and commercial application for plug-in hybrid electric vehicles and other electric drive transportation technology, including activities with respect to—

(1) high capacity, high efficiency batteries, to—

(A) improve battery life, energy storage capacity, and power delivery capacity; and

(B) improve manufacturability, and to minimize waste and hazardous material production in the entire value chain, including after the end of the useful life of the batteries;

(2) high efficiency onboard and offboard charging components;

(3) high power drive train systems for passenger and commercial vehicles and for supporting equipment;

(4) onboard power control systems, power trains, and systems integration for plug-in hybrid

electric vehicles, flexible fuel plug-in hybrid electric vehicles, and hybrid electric vehicles, including—

(A) development of efficient cooling systems; and

(B) research and development of onboard power control systems that minimize the emissions profile of such vehicles; and

(5) lightweight materials research and development—

(A) to reduce the weight of light and heavy duty vehicles to improve fuel efficiency without compromising passenger safety; and

(B) to reduce the cost and improve the manufacturability of lightweight materials (such as steel alloys and carbon fibers) required for the construction of lighter-weight vehicles.

(c) PLUG-IN HYBRID ELECTRIC VEHICLE PILOT PROGRAM.—

(1) ESTABLISHMENT.—The Secretary shall establish a plug-in hybrid electric vehicle demonstration and commercial application competitive grant pilot program to provide not more than 25 grants annually to State governments, local governments, metropolitan transportation authorities, or combina-

tions thereof to carry out a project or projects for the purposes described in paragraph (2).

(2) GRANT PURPOSES.—Grants under this subsection may be used to acquire plug-in hybrid electric vehicles, including passenger vehicles.

(3) APPLICATIONS.—

(A) REQUIREMENTS.—The Secretary shall issue requirements for applying for grants under the pilot program. At a minimum, the Secretary shall require that applications shall include—

(i) a description of the project or projects proposed in the application, including an explanation of how they meet the requirements of this section;

(ii) an estimate of the air pollution emissions reduced and fossil fuel displaced as a result of the project or projects proposed in the application, and a plan to collect and disseminate environmental data related to the project or projects over the life of the project or projects;

(iii) a description of how the project or projects proposed in the application will be sustainable without Federal assistance after the completion of the term of the grant under this subsection; and

(iv) a complete description of the costs of each project proposed in the application, including acquisition, operation, and maintenance costs over the expected life of the project or projects, including after the completion of the term of the grant under this subsection.

(B) PARTNERS.—An applicant under subparagraph (a) may carry out a project or projects under the pilot program in partnership with one or more private entities.

(4) SELECTION CRITERIA.—In evaluating applications under the pilot program, the Secretary shall consider each applicant's previous experience involving plug-in hybrid electric vehicles and shall give priority consideration to applications that—

(A) are most likely to maximize protection of the environment; and

(B) demonstrate the greatest commitment on the part of the applicant to ensure funding for the proposed project or projects and the greatest likelihood that each project proposed in the application will be maintained or expanded after Federal assistance under this subsection is completed.

(5) PILOT PROJECT REQUIREMENTS.—

(A) MAXIMUM AMOUNT.—The Secretary shall not provide more than $20,000,000 in Federal assistance under the pilot program to any applicant for the period encompassing fiscal years 2007 through fiscal year 2016.

(B) COST SHARING.—The Secretary shall award grants under this subsection on a competitive basis. Awards under this subsection shall be for a maximum of—

(i) $10,000 per vehicle in fiscal years 2007 through 2009;

(ii) $8,000 per vehicle in fiscal years 2010 through 2012;

(iii) $6,000 per vehicle in fiscal year 2013;

(iv) $3,000 per vehicle in fiscal year 2014;

(v) $2,000 per vehicle in fiscal year 2015; and

(vi) $1,000 per vehicle in fiscal year 2016.

(C) TRANSFER OF INFORMATION AND KNOWLEDGE.—The Secretary shall establish mechanisms to ensure that the information and knowledge gained by participants in the pilot program are transferred among the pilot program participants and to other interested parties, including other applicants.

(6) SCHEDULE.—

(A) PUBLICATION.—Not later than 90 days after the date of enactment of this Act, the Secretary shall publish in the Federal Register, Commerce Business Daily, and elsewhere as appropriate, a request for applications to undertake projects under the pilot program. Applications shall be due within 180 days of the publication of the notice.

(B) SELECTION.—Not later than 180 days after the date by which applications for grants are due, the Secretary shall award grants through a competitive, peer reviewed process.

(d) MERIT BASED FEDERAL INVESTMENTS.—Research, development, demonstration, and commercial application activities carried out by the Department of Energy under this Act shall be awarded consistent with section 988(a) through (d) and section 989 of the Energy

Policy Act of 2005 (42 U.S.C. 16352(a) through (d) and 16353).

(e) AUTHORIZATION OF APPROPRIATIONS.—There are authorized to be appropriated to the Secretary—

(1) for carrying out subsection (b), $250,000,000 for each of fiscal years 2007 through 2016, of which up to $50,000,000 may be used for the program described in paragraph (5); and

(2) for carrying out subsection (c), $50,000,000 for each of fiscal years 2007 through 2016.

SECTION-BY-SECTION DESCRIPTION OF THE DISCUSSION DRAFT

Sec. 1. Short Title.

The Plug-In Hybrid Electric Vehicle Act of 2006.

Sec. 2. Near-Term Vehicle Technology Program.

a. Definitions.

Defines terms used in the text.

b. Program.

Requires the Secretary of Energy to carry out a program of research, development, demonstration, and commercial application for plug-in hybrid electric vehicles and electric drive transportation technology.

Requires the Secretary of Energy to ensure that the research program is designed to develop

- high capacity, high efficiency batteries with:
    - improved battery life, energy storage capacity, and power discharge;
    - enhanced manufacturability; and
    - minimized of waste and hazardous material use throughout the entire value chain, including after the end of the useful life of the batteries.
- high efficiency on-board and off-board charging components;
- high-power drive train systems for passenger and commercial vehicles;
- on-board power control systems, power trains, and system integration research for all types of hybrid electric vehicles, including:
    - development of efficient cooling systems; and
    - research and development of on-board power control systems that minimize the emissions profile of plug-in hybrid drive systems.
- lightweight materials to:
    - reduce vehicle weight and increase fuel economy while maintaining safety; and
    - reduce the cost and enhance the manufacturability of lightweight materials used in making vehicles.

c. Plug-in Hybrid Electric Vehicle Pilot Program.

(1) Requires the Secretary of Energy to establish a pilot program for the demonstration and commercial application of plug-in hybrid electric vehicles. The pilot program would provide no more than 25 grants annually to State governments, local governments, metropolitan transportation authorities, or a combination of these entities.

(2) Grants will be used to acquire plug-in hybrid electric vehicles, including passenger vehicles.

(3) Requires the Secretary to issue requirements to apply for grants under the pilot program and sets minimum requirements for applications, including cost estimates and a description of how the project will continue after federal assistance ends.

(4) Requires the Secretary to consider the following criteria in reviewing applications:
- prior experience involving plug-in hybrid electric vehicles;
- project or projects that are most likely to maximize protection of the environment; and
- project or projects that demonstrate the greatest commitment on the part of the applicant to ensure funding for the proposed project or projects and the greatest likelihood that each project proposed in the application will be maintained or expanded after federal assistance under this program is completed.

(5) Requires the Secretary to provide no more than $20,000,000 in federal assistance under the pilot program to any single applicant for the period encompassing fiscal years 2007 through fiscal year 2016.

Requires that grants awarded by the Secretary do not exceed the annual maximum per-vehicle amounts as follows:

Annual Maximum Grant per Vehicle

FY07 – FY09	FY10 – FY12	FY13	FY14	FY15	FY16
$10,000	$8,000	$6,000	$3,000	$2,000	$1,000

Requires the Secretary to establish mechanisms to ensure that the information and knowledge gained by participants in the pilot program are transferred among the pilot program participants and to other interested parties, including other applicants.

(6) Requires the Secretary to widely publish requests for proposals related to this grant program and to begin awarding grants no later than 180 days after the date by which applications for grants are due. Requires the Secretary to award grants through a competitive, peer reviewed process.

d. Merit based federal investments.

Requires the Department of Energy to ensure that the funding for the activities in this section are awarded consistent with the merit based guidelines for federal energy R&D investments established in the *Energy Policy Act of 2005* (EPACT) (P.L. 109–58).

e. Authorization of Appropriations.

Authorizes appropriations to the Secretary of Energy of $250 million for each of fiscal years 2007 through 2016 to carry out the program of research, development, demonstration, and commercial application for plug-in hybrid electric vehicles and electric drive transportation technology. Of the $250 million, $50 million may be used for lightweight materials research and development as described in subsection (b)(5).

Authorizes appropriations to the Secretary of Energy of $50 million for each of fiscal years 2007 through 2016 to carry out the plug-in hybrid electric vehicle pilot program.

DOE Workshop on Plug-In Hybrid Electric Vehicles Discussion Issues and Questions

U.S. DEPARTMENT OF ENERGY
MAY 4–5, 2006
WASHINGTON, DC

Hybrid vehicles with the ability to operate in an electric-only mode and recharge from an electric outlet (referred to as "plug-in hybrids") have received a great deal of attention recently because of their energy supply flexibility, ability to reduce petroleum consumption and potential environmental benefits. Plug-in hybrids are described in the Advanced Energy Initiative, announced by President Bush in the State of the Union Address, as a way to increase fuel efficiency and utilize spare electric generating capacity at night as well as being "a practical step toward hydrogen fuel-cell vehicles, which have some of the same electric-drive and power-management technologies."

The Department of Energy (DOE) conducts research and development on a variety of complementary (and competing) technologies to meet its energy efficiency and renewable energy objectives, including hybrid propulsion systems. As a precursor to supporting plug-in hybrid technology research, DOE must consider:

- What are the technical and economic merits of plug-in hybrids within the candidate set of fuels and powertrains of the future?
- What should be the basis for comparison to other fuel/powertrain combinations? (e.g., oil use, greenhouse gas emissions, criteria pollutants, flexibility of fueling and energy sources, utilization of electricity to enhance efficiency, cost)

Answers to these questions are complex due to the potential interdependencies among the elements of the system—including the vehicle, the recharging infrastructure and the electric utility power plant. This paper sets the stage for discussion among DOE, industry and academia by beginning to identify opportunities and impediments, summarizing the status and applicability of critical technologies and posing key questions about system elements and their interactions.

Workshop Objectives

The following workshop objectives are expected to lead to suggestions for R&D and to establish a framework for continuing dialogue:

1. Identify the state-of-the-art of current technologies that may have direct application to plug-in hybrids and related energy technologies.
2. Identify research gaps and their relative importance.
3. Identify possible research roles of the Federal Government, industry and academia.
4. Establish a technology baseline and develop sets of plug-in hybrid vehicle architectures to be evaluated.
5. Begin a dialogue among hybrid vehicle designers/producers, electric utilities and researchers for the purpose of specifying mutually desirable plug-in hybrid and utility attributes.
6. Identify the value proposition (for both the customer and manufacturer) that would allow the widespread application and adoption of plug-in technology.

Why Plug-in Hybrids?

Advocates have offered the following reasons for government and industry to support the development and deployment of plug-in hybrids:

Oil savings. Since very little oil is used in the production of electric power, switching to electric drive using energy from the grid can result in significant reductions of oil use.

Greenhouse gas reductions. With the use of carbon sequestration for electricity from coal, nearly all methods of generating electricity should result in reduced greenhouse gases via use of grid electric power. The reductions would be dramatic for electricity generated from nuclear, hydro and renewable sources.

Zero (tailpipe) emissions. Electric drive via plug-in hybrids charged overnight displaces emissions in time and space. Displacement of daytime emissions to nighttime should reduce ozone, since sun and precursor pollutants are necessary to cause this air pollutant. Displacement of emissions from urban to rural areas could reduce net population exposure, even if total emissions do not drop. Although total emissions from coal-fired power plants for some pollutants could increase, use of electricity in most cases could reduce total emissions, in addition to reducing urban emissions. And finally, emissions produced by vehicles prior to warm-up could be greatly reduced with electric operation.

Energy savings. Plug-in hybrid advocates have noted that grid-sourced electric vehicle operation may provide the lowest full-fuel-cycle energy use when compared to other transportation technologies. This could enhance the long-term energy supply.

Electric utility efficiency. "Load leveling," the concept of filling the nighttime trough in electric demand by shifting electricity use to this period, can enhance both economic and thermal efficiency of electric utilities. Economic efficiency in the short run is enhanced because capital (power plants and the grid) is more efficiently used and generating efficiency is improved by operating plants at steady, near optimum conditions instead of cyclic operation to match varying demand. In the long-term as more generating capacity is needed, nuclear and efficient fossil fueled combined cycle power plants could be added. From another perspective, relatively low cost, clean wind power and overnight charging match each other in time reasonably well. In the long run some see a bi-directional flow of power between plug-in hybrids and the grid, with the batteries used for further load leveling and to improve the viability of intermittent wind.

Emergency services. Some see the plug-in hybrid as a potential clean, quiet backup electric generator for the home in the event of power outages. A more expansive view is that plug-in hybrids could be connected to a grid that could carry power of many vehicles as a utility's back-up for power plant outages. Plug-in hybrids could also provide reserve assurance that, in the event of a long-term shortage of oil, the most valuable transportation services could be maintained by domestic fuel supplies powering the grid.

Challenges

Despite the numerous anticipated benefits of plug-in hybrids, implementation of any complex transportation technology is difficult, time consuming and costly. *Details matter.* If the cost is too high, the anticipated benefits may not be realizable.

Battery technology. Perhaps the most important 'detail' is the battery, as recognized in the State of the Union Address, with notable technical barriers to achieving the energy capacity for a reasonable electric range, the power needed for acceptable performance in all operating modes and life comparable to that of the vehicle—all at a reasonable cost. Consumers are aware of the benefits of conventional hybrid vehicles and plug-in hybrids sound even more attractive due to the higher fuel economy potential. But today's batteries are capable of only one to two miles electric range, as stated in the Advanced Energy Initiative, not enough to realize meaningful fuel economy improvements. And, when subjected to the deep discharges required for long electric range in a plug-in hybrid, batteries will probably not last as long as in a conventional hybrid (e.g., typical eight-year/80,000 mile warranty). *Current battery technology could be a show-stopper for plug-in hybrids.*

Electric drives. Another technical detail worth noting is that *current production hybrid vehicles cannot be used as plug-in hybrids* without reduced performance in their all-electric mode. Electric drives in production hybrids have been optimized for intermittent use—to assist the engine during peak demands. They are not powerful enough to provide the same acceleration or top speed without the engine and are not designed to handle the temperature rise caused by continuous operation. Production hybrids cannot be easily adapted to remove this limitation because the motors/generators are highly integrated. The power of both the electric motor and power electronics must be increased substantially (up to 100 percent) to provide comparable performance. This is not a show-stopper for a new vehicle design, but it will add cost and exacerbate packaging issues.

Interdependencies with utilities. The most obvious interdependency is the need for plug-in hybrid vehicles to communicate with and (perhaps) be controlled by the utility during charging for the most effective electric energy utilization. Beyond that, the requirements and benefits of the relationship are not as clear. For example, the choice of powertrain technology could have a regional dependency—a vehicle for urban areas with air quality problems might not be the best choice for the Nation as a whole, where priorities other than air quality would dominate. There are many possible alternative powertrain configurations and priorities (on both the supply and demand sides) that could alter design choices. In addition, the optimum mid- and long-term sources of energy are not obvious. Wind and nuclear power might compete to be the option that fills a nighttime trough in demand to meet charging needs—though neither may be the best choice at this time.

A solid R&D roadmap needs to be developed if success is to be achieved. The following discussions illustrate the numerous challenges that exist. Using these discussions as a starting point, it is expected that the attending experts will help determine research gaps, identify omissions, and provide recommendations on answering the important questions.

Hybrid Vehicle Systems

Current Status

- Current hybrid vehicles are designed to rely heavily on the engine with *intermittent use of the electric propulsion system*—to assist the engine during peak power demands, capture regenerative braking energy and, in some cases, provide low-speed electric driving.
- Battery, motor and power electronics are sized to provide part of the propulsion power on an intermittent basis.
- Cost in comparison to conventional vehicles appears to be an important impediment to large scale production and sales.
- The propulsion system control strategy is focused on fuel economy, emissions reduction and protection of the battery (i.e., limited to shallow discharge-charge cycles to maximize life).
- Tools and procedures for analysis (i.e. modeling and simulation) and testing (laboratory and field) for technology development and validation are in place. Regulatory test procedures are defined based on standard driving cycles.

Applicability to Plug-in Hybrids

- Plug-in hybrids have been proposed with a variety of vehicle architectures, ranging from the present power sharing configurations (with the addition of external charging capability) to vehicles with substantial electric-only range and *intermittent use of the engine.*
- The battery must be sized (higher energy) for the desired electric range.
- The electric motor and power electronics must be sized (higher power) for desired performance in the electric-only mode.
- Cost must be competitive; a higher power and energy electric propulsion system will exacerbate the production cost differential relative to conventional vehicles.
- Present control strategies are not applicable—revision is needed to focus on electric range and a daily use pattern that includes external charging.
- Analytical tools require revision to account for mutually exclusive or power sharing operating modes and daily use patterns. Existing HEV test procedures to measure and report fuel economy are not applicable to a vehicle with substantial electric range and a daily use pattern that includes overnight and/or opportunity charging.

Technical Gaps

- **Vehicle analysis—**Duty cycles (consistent with consumer use patterns and proposed test procedures) and projected component characteristics are needed to design vehicles, specify components and evaluate options.
- **Control strategy—**Algorithms need to be refocused to maximize petroleum displacement as a function of the vehicle configuration, on-board energy storage and interaction with the electric utilities.
- **Testing—**Test procedures that reflect daily driving and charging patterns are needed to support benchmark testing (to identify key performance requirements for component development) and technology validation.

Key Questions

1. **What is the definition of 'electric range' for a plug-in hybrid?**
   Continuous or cumulative electric-mode operation (e.g., will intermittent engine operation be allowed in the determination of range)?

2. **What are the design trade-offs among cost, configuration, control strategy, battery power and energy requirements?**

   Is the same vehicle performance necessary in hybrid and electric modes?

   What electric range provides the best cost-benefit ratio at the vehicle level?

   Can available battery technology meet the needs of a plug-in hybrid?

   Can ultra-capacitors be used for additional power?

   Can control strategy compensate for near-term energy/power limitations of the electric propulsion system?

3. **How will consumers utilize the electric range (i.e., battery energy) and recharge the battery on a daily basis?**

   From a customer perspective, is opportunity charging a realistic alternative to longer electric range (i.e., a larger battery)?

   How does use pattern and control strategy impact battery life and life cycle cost?

   What duty cycles/daily patterns are appropriate for analysis (i.e., modeling and simulation of vehicle/propulsion system alternatives)?

4. **Is plug-in technology applicable to and beneficial for varying vehicle types?**

   Will plug-ins be beneficial in all regions of the country?

   Will plug-in powertrains be viable for a range of platforms (S, M, L, and XL) and appeal to a range of customers (performance and/or economy)?

5. **How will plug-in hybrids be tested?**

   Since plug-ins will use both liquid fuel and electric energy (perhaps with limited use of the engine), how should fuel economy be measured and reported?

   What test cycles and procedures should be used?

   Since plug-in hybrids could use both overnight and opportunity charging, should a daily driving cycle be considered?

6. **What is the value proposition for the customer and manufacturer?**

   Why would a customer buy a plug-in hybrid?

   Why would the manufacturer invest to develop and produce plug-in hybrids?

   Some believe that a $1300 cost differential or a three-year payback is necessary for hybrids to have mass market appeal—will this be different for plug-in hybrids?

7. **Will the requirement to plug in and/or the plug-in limitations (e.g., availability of 220V outlet, charge rates/times) limit the market?**

Energy Storage Technology

Current Status

- The typical battery in a production hybrid vehicle is a nickel-metal hydride (NiMH) sized for power demands, i.e., start/stop functionality, power assist during acceleration, recovering regenerative braking energy and supporting some low-speed driving.
  - Energy capacity provides only a few miles all-electric range (at reduced performance).
  - Service life appears to fall short of vehicle life, even if the state-of-charge is maintained within a relatively narrow range (i.e., not discharged deeply). Manufacturers employ a control strategy to ensure this type of operation and provide warrantees accordingly (e.g., eight years/80,000 miles).
  - DOE has performed limited testing with NiMH in a production hybrid with a plug-in duty cycle and the results have been extrapolated to estimate battery requirements for various electric ranges. In addition, NNE batteries have been used in an after-market modification of a production hybrid to demonstrate the impact of the plug-in concept on fuel economy.
- Lithium-ion (Li-ion) batteries, being developed by DOE and considered by some manufacturers for conventional hybrid vehicle applications, are currently used in consumer electronics exclusively.

- ○ Life tests have successfully demonstrated 300,000 shallow charge-discharge cycles, likely adequate for conventional power-assist hybrids.
- ○ Currently they are considered two to four times too expensive for vehicles.
- ○ Li-ion batteries have been incorporated in a plug-in hybrid concept vehicle by a major manufacturer and analyzed by DOE for use plug-in hybrids; the higher specific energy and power illustrated potential advantages relative to NiMH.

- Other technologies, such as ultra-capacitors (low energy/high power density) and Li-metal batteries (high energy, but short life) are being investigated by DOE.

Applicability to Plug-in Hybrids

- Analysis and testing with NiMH batteries in current production hybrid vehicle configurations indicates the potential for high fuel economy, but their service life with a plug-in vehicle duty cycle (including deep discharge cycles) is unknown.
- Li-ion batteries could perform better than NiMH in plug-ins due to their higher specific energy and power. In addition, they are potentially less expensive and could last longer, but similar to NiMH, their service life with deep discharge cycles has not been demonstrated.

Technical Gaps

- **Cost** of Li-ion batteries must be reduced by 50–75 percent; cost drivers (raw materials and processing, cell and module packaging) are being addressed.
- **Life** with combined deep/shallow cycling as in plug-in hybrid vehicle use needs to be determined for all batteries; 15-year calendar life target not demonstrated.
- **Safety—**Li-ion batteries are not intrinsically tolerant of abusive conditions (short circuits, overcharge, over-discharge, crush or exposure to fire) and currently require mechanical and electronic devices for protection; implications of plug-in recharging remain to be determined.
- **Low-temperature operation** of Li-ion batteries needs to address poor discharge characteristics and failure modes during charge.

Key Questions

1. **What is required of the battery to support plug-in hybrids?**
   What is the optimum power-energy ratio?
   What is the allowable weight and volume?
   What are the trade-offs among service life, deep and shallow cycling?
   Can available batteries be utilized in near-term plug-in hybrids?
   Is dual energy/power storage applicable (e.g., battery + super capacitor)?
   Could plug-in batteries be modularized to provide broader cost benefit to the consumer?
2. **How should plug-in hybrid batteries be bench tested?**
   What cycling profiles match potential vehicle architectures?
   Will daily cycles (with overnight and/or opportunity charging) be incorporated into the test regime?
   Is accurate determination of state-of-charge (SOC) complicated by a plug-in hybrid duty cycle?

Electric Motors and Power Electronics

Current Status

- Electric drive motors and power electronics currently in production hybrid vehicles are *designed for intermittent operation,* i.e., sized for the power requirements, duty cycle and thermal loads to assist the engine during peak demands, convert braking energy, charge the battery and, in some cases, provide low speed driving.

- Drive motors/generators are typically optimized for and integrated within the drivetrain. Typical drive motors in production hybrids are rated at about 50 kW (~1500 rpm) and the latest introductions are up to 100 kW (~4500 rpm)—both about half the maximum power of their respective propulsion systems. "Upgrading" these systems for electric-only operation, i.e., increasing the peak and average power and thermal loads, is not likely due to the packaging and thermal limitations.
- Power electronics are designed to match the characteristics of the energy storage subsystem and the drive motor. Batteries are nominally 200–250V, with power electronics operating at 500–600V max (using a boost converter) to decrease the current and associated losses. Consequently, the power semi-conductors are rated at about twice that voltage.

Applicability to Plug-in Hybrids

- Several powertrain architectures are being considered for plug-in hybrids. The power-assist configuration with a modified control strategy to allow battery depletion would have the least impact on the motor and power electronics. The architecture presenting the greatest challenges is the dual-mode with equal performance in both modes. Current production hybrid motors and power electronics—optimized for intermittent use and supplying about half the max power—cannot operate in a continuous electric-only mode with full performance due to the inherent power and thermal limitations.

Technical Gaps

- Motor power must be increased (perhaps doubled) for continuous operation in full-performance dual-mode vehicles, which could require further increases in maximum motor speed and constant power speed range.
- Power electronics must be resized (or redesigned) to allow higher continuous ratings, putting pressure on packaging and efficiency. Voltage may have to increase to 800V or more and the associated silicon devices may need to be rated at 1440V to 1700V.
- Thermal management issues are exacerbated because the electric drive duty cycle is a larger fraction of vehicle propulsion. Electrolytic capacitors may have to be replaced with film capacitors—more expensive, but more tolerant of higher temperatures. Liquid cooling may be required.

Key Questions

1. **Are motor and/or power electronics issues unique to plug-ins?**

   What types of motors are best suited to various plug-in hybrid configurations, and how do they differ from conventional HEVs and fuel cell vehicles?

   What motor R&D is most needed to realize commercially viable plug-in hybrid systems?
2. **What are the thermal system requirements (heat rejection, component and subsystem sizing, coolant temperatures, etc.) for motor and power electronics in plug-in hybrids?**
3. **What are the implications of dual energy storage (e.g., battery + super capacitor), including the performance degradation of each at low ambient temperatures?**

Recharging Infrastructure

Current Status

- Nearly all houses are equipped with 110VAC/15A circuits throughout, capable of supplying up to 10 kWh in a six-hour period.
- Modern houses have 220VAC/20A circuits (capable of supplying up to 26 kWh in six hours) for hard-wired appliances such as the range or water heater.
- Not all residences are single family homes with a garage or carport.

Applicability to Plug-in Hybrids

- Examples: A 110VAC outlet could recharge a vehicle with a 15–20 mile range and a 220VAC outlet could support a vehicle with a 40–50 mile range (assuming energy consumption of 500Wh/mi and an 85 percent efficient six-hour charge for both).

Technical Gaps

- The most efficient nighttime charging (from the utility perspective) will require a communication link with the vehicle to control the charge time and the power available, in addition to metering (if preferential pricing for vehicles is offered).
- Appropriate circuits in convenient vehicle charging locations (e.g., garages, parking lots and structures)—220VAC for longer electric ranges.

Key Questions

1. **What changes to customers' electrical systems are required to recharge?**

   What is a reasonable amount of time to charge?

   Should there be a standard interface (for power, communication and control)?

   What is the impact of more than one vehicle per customer/residence?

   How many customers can take advantage of a plug-in hybrid (due to parking location)?

   What is the impact on local substations as well as the utility in general?

2. **How would plug-in hybrids impact/benefit the utility?**

   How many plug-in hybrids can a utility support?

   How difficult is communication with and controlled charging of plug-in hybrids?

   What benefits can be realized from plug-ins returning energy to the grid?

   How many vehicles are necessary and/or desirable for the utility to implement distribution system modifications?

   Would plug-in hybrids affect grid quality? If so, how important is this and how costly might a fix be?

Electric Power Plant

Current Status

Present power plants are fueled by a variety of fuels across the country:

- Natural gas—clean and efficient, but no longer thought to be abundant in the United States.
- Coal—Abundant, but present technology (with the exception of integrated gasification combined cycle (IGCC)) is not considered the clean alternative; DOE is undertaking CO_2 sequestration R&D in the FutureGen Initiative.
- Nuclear—Present capacity operating at very high load factors.
- Wind—Turbines produce more power at night when vehicle battery charging needed most; regionally variable and limited supply but relatively cheap to install.
- Solar—Photovoltaic arrays not competitive except in areas not served by the grid.

Applicability to Plug-in Hybrids

- Nuclear—Unlikely spare capacity would be used in the near-term due to high load factor, load leveling with plug-ins might enhance economic viability in the future.
- Wind—Should benefit from plug-ins, which can match supply and demand, minimizing the initial impact on existing utilities.
- Solar—Mismatch with overnight charging, but perhaps long-term source (i.e., central or distributed arrays at business locations) for opportunity charging.

Key Questions

1. **What are the regional impacts and benefits of plug-in hybrids?**

   Where is the extra capacity to charge plug-in hybrids, when is it available and is there fuel to support it?

Does this change in the long-term?

Could additional demand for plug-in hybrids be met with additional capacity planned for normal demand growth?

What is the impact of variation in electricity cost and price?

How would local and total emissions/air quality be affected by plug-in hybrids?

2. **Can renewable sources play a significant role?**

   Is there an adequate match of producers (e.g., wind farms) and vehicles in a region to make this a viable entry strategy or a long-term option?

3. **How important are the 'emergency provisions' of a plug-in hybrid to the value proposition (considering the customer and utility)?**

   What is the value of the grid connection in an oil shortage?

   What is the value of the auxiliary power capability in a power outage?

   How would use in an emergency situation affect grid operations or power quality?

   To what extent would fixing power quality issues raise technology cost?

Argonne NATIONAL LABORATORY

Broad Overview of Plug-in Hybrids and Analytical Studies

Presented at:

DOE PHEV Discussion Meeting

May 4-5, Washington DC

Danilo J. Santini

Section Leader, Technology Analysis

Center for Transportation Research

Sponsor: Office of Freedom Car and Vehicle Technologies

U.S. Department of Energy

E. Wall, Program Manager, Office of Freedom Car and Vehicle Technologies

T. Duong, Team Leader, Vehicle Systems Technologies

THE UNIVERSITY OF CHICAGO Office of Science

Argonne National Laboratory is managed by The University of Chicago for the U.S. Department of Energy

Topics

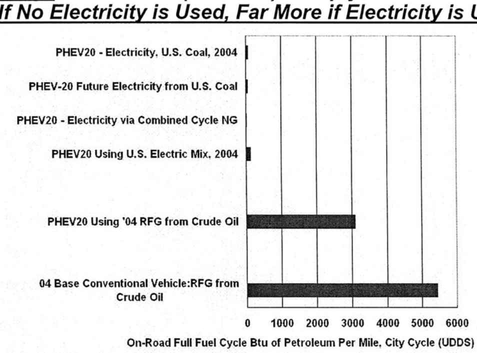
- Why the expanding interest in PHEVs?
- Would massive success with PHEVs stress power generation?
- Would massive success stress the grid?
- What new sources of power would be favored for expansion?
- How does the pattern of driving interact with PHEV design?
- How would successful R&D, achieving cost reduction, affect patterns of PHEV preference?
- Is a shift of preferred HEV/PHEV battery chemistry underway?
- Illustrations of some of the technical problems to address
- Have PHEVs jumped into public consciousness?
- Provide a closing list of important questions to discuss

2

Why *more* interest in plug-in hybrids with new EPACT legislation authorizing new government/industry programs?

- **Oil savings** (heightened interest due to oil price increases)
  - "our nation is addicted to oil" President Bush
  - EERE priority – improve energy security by reducing oil imports
- Focus of 2001 studies: CA desire for zero tailpipe emissions
- Greenhouse gas reductions (cumulative climate change science)
- Electric utility efficiency (load leveling)
- Emergency services (hurricanes, power failures, spot gasoline shortages)
- Improvements in li-ion battery technology
  - (li-ion eclipses NiMH in consumer electronics)

Oil Savings: Each PHEV (Full HEV) Sharply Reduces Oil Use Even If No Electricity is Used, Far More if Electricity is Used



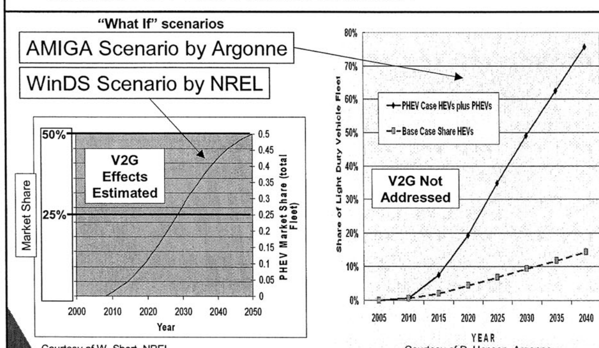
Oil Use, Electric Generation Expansion, Change in Power Plant Mix and Greenhouse Gases With PHEVs in Future Decades:

2 Current National Lab PHEV Initial Scenario Analyses

(Others coming from EPRI, more from National Labs)

5

What Could The Effect on Oil Use, Electric Generation, and Carbon Emissions Be <u>if Massive</u> Success of PHEVs Were Achieved?



6

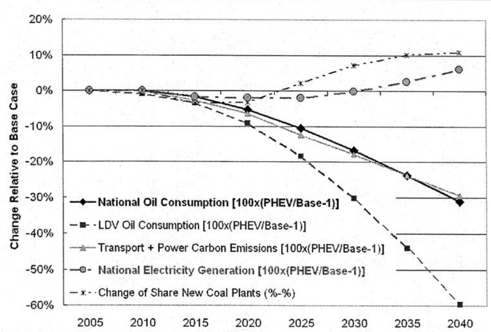
Massive Success Requires a Few Percent Increase in Total Generation, Leads to Significant Use of Wind Power

Summary of 2050 WinDS/PHEV Results – PHEV Cases Compared to Base Case

2050 Projected Values	Base Case (no PHEVs)	PHEV-20 Case	PHEV-60 Case
Gasoline use (Billions of Gallons)	368	255 (31% decrease)	212 (43% decrease)
Wind Generation (TWh/year)	757	853 (13% increase)	1554 (105% increase)
Total Load (TWh/year)	9392	9808 (4.4% increase due to PHEV load)	10082 (7.3% increase due to PHEV load)
Increase of Wind Electricity vs. Base Case	-	0.6%	7.5%
Total Installed Generation Capacity (GW)	2161	2092	1972
Generation from Coal (TWh/year)	8272	8597 (3.9% increase)	8169 (1% decrease)
Electric and Light Duty Transport Sector CO2 (Million Tons CO2/year)	10956	9910 (9.5% decrease)	9346 (14.7% decrease)

Courtesy of W. Short, NREL 7

With A Higher PHEV Penetration Scenario Than in WinDS, AMIGA Obtains Higher Oil Savings (also by Including Coal-to-Liquids for Co-Production of Diesel Fuel and Electricity)



Courtesy of D. Hanson, Argonne 8

What Should be Assumed to be the Long Term Marginal (Incremental) Source of PHEV Electricity?

PREDICTED CONTRACTING & STABLE SHARES IF PHEVs SUCCEED

- Coal: AMIGA and WinDS PHEV60 cases predict reduced coal use
- Nuclear: WinDS decline, AMIGA steady production share
- Oil and Gas: WinDS uses AEO declines for "oil-gas-steam" power plants, and assumed a high gas price, shrinking other natural gas

PREDICTED INCREASING SHARES

- Wind
  - Both AMIGA and WinDS predict more expansion of wind than natural gas or "other" (renewable) power generation
- Other (hydro, biomass, geothermal, waste to electricity, solar)
  - AMIGA predicts an increase
- Natural Gas
  - AMIGA predicts some expansion of natural gas

9

PNNL Electric Infrastructure Capability Study Early Findings Show >> National Reserve Capacity to Serve PHEVs Than Needed, But ...

Preliminary conclusions:

- Idle grid capacity (generation, T&D) is adequate to supply ~50% - 65% (or more) of energy for U.S. cars and light trucks at hybrid performance levels
- There are significant regional differences based on varying reserve margins across regions
- Todays' CO_2 impacts approximately neutral for today's baseload and intermediate plants (10% above or below current emissions depending on region)
- Significant issues for coordinating vehicle charging with grid peak loads, reliability needs, and market and other signals

Courtesy of R. Pratt, PNNL 10

Prior EPRI and/or Argonne Studies (2001) Examined the Following Questions

- **Ni-MH batteries (too pessimistic on power)**
- **20 and 60 mi. of EV range (CARB credit kink points)**
- **CAFE MPG assumptions (too optimistic on electric miles?)**
- **Variation in battery cost as function of kW/kWh ratio**
- **Charge depletion to achieve ZEV range operating as EV**
- **Consumer preferences, given education about HEVs**
- **Effects of requiring a range of 0-60 times (12, 10, 8 sec.)**
- **Effects of varying powertrain costs on marketability**
- As EV, approximate capability to match US06 driving schedule
- Automated manual transmissions in HEVs
- Minimum sustainable top speed, PNGV gradeability minimum
- Economics of series vs. parallel HEV (parallel superior)
- Effects of a reduced load glider on mpg of HEV vs. CV (like the Prius)
- Total fuel cycle pathway emissions

11

Average National Miles Per Day ~ 30 Miles, Typically Composed of Several Short Trips

- Instrumented vehicle results
  - Baltimore 4.0-5.9 mi.- average of 4.9
  - Spokane 3.6 mi.
  - Atlanta 6.0 mi.
- EPA MOVES 2004 assumptions
  - Passenger cars: 4.4 mi., 7 starts/ average day
  - Light trucks < 6000 lb: 4.8 mi., 7 starts/ average day
  - Light trucks > 6000 lb: 4.6 mi., 7 starts/ average day

Derivative questions relating to PHEV design, benefits:

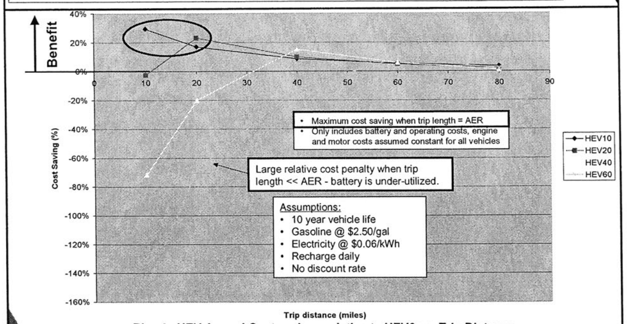
How many of the 7 starts are "cold"?

How many of the trips could be in EV mode?

What is top speed of short trips?

12

NREL Investigation of Cumulative Costs Indicates Shorter Ranges Offer More Consistent Benefits. Customer Needs For Range Will Differ Significantly



Plug-in HEV Annual Cost savings relative to HEV0 vs. Trip Distance (73% DOD window) as a percentage of HEV0 Annual Costs

Source: Plug-in HEVs: A Near-Term Option to Reduce Petroleum Consumption. T. Markel et al. NREL 05 Milestone Report, Jan. 19, 2006.

13

EPRI Surveyed Consumers in Major Urban Areas About Preferences for HEVs, PHEV20s, and PHEV60s

- Boston, Atlanta, Phoenix, Los Angeles
- 60 trade off questions for nine attributes of HEVs
- Respondents were separated into "commute bins"
  - 0-5 miles (28% of sample) 7700 miles/yr
  - 5-15 miles (30% of sample) 11900 miles/yr
  - >15 miles (42% of sample) 17975 miles/yr

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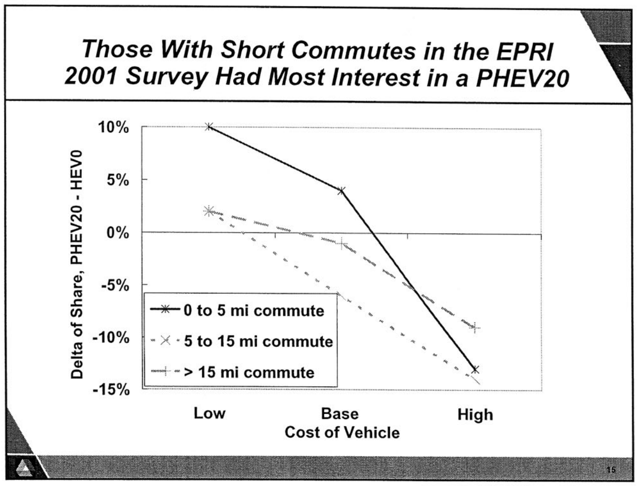
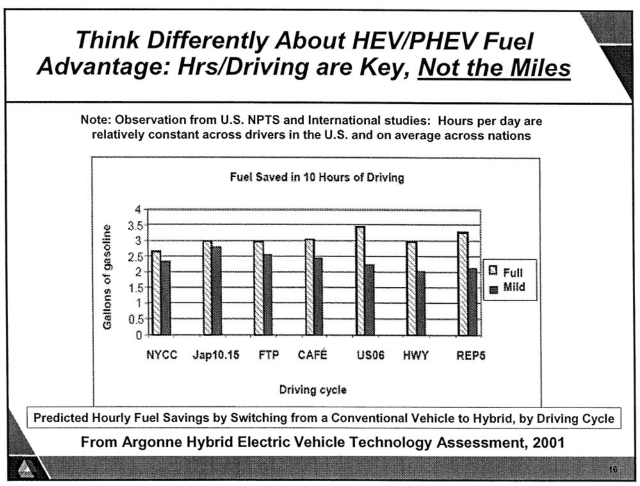
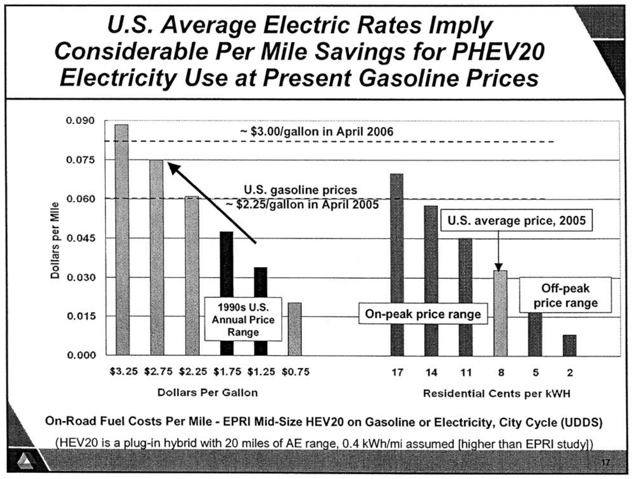
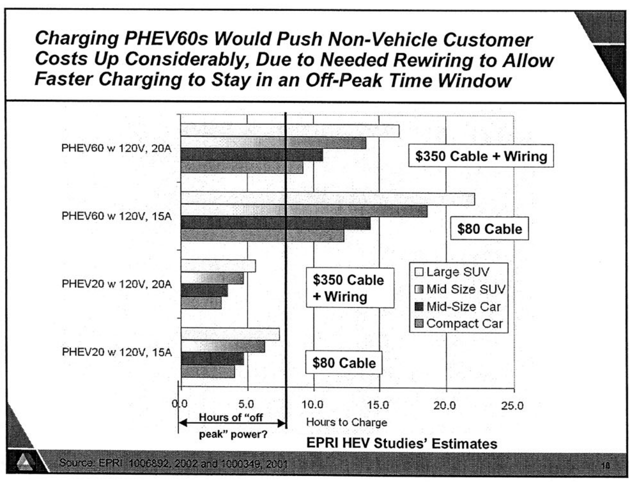
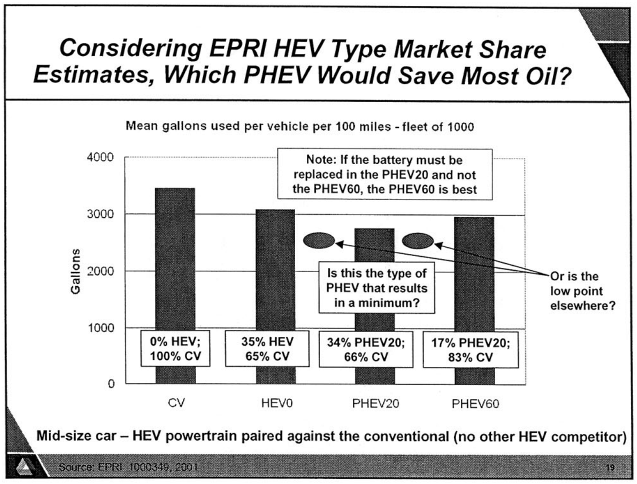
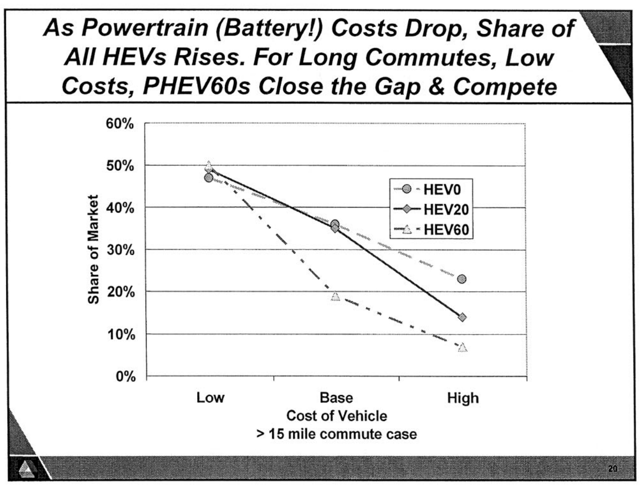

Those With Short Commutes in the EPRI 2001 Survey Had Most Interest in a PHEV20
Delta of Share, PHEV20 - HEV0
10%
5%
0%
-5%
-10%
-15%
0 to 5 mi commute
5 to 15 mi commute
> 15 mi commute
Low
Base
High
Cost of Vehicle
15


Think Differently About HEV/PHEV Fuel Advantage: Hrs/Driving are Key, Not the Miles
Note: Observation from U.S. NPTS and International studies: Hours per day are relatively constant across drivers in the U.S. and on average across nations
Fuel Saved in 10 Hours of Driving
Gallons of gasoline
4
3.5
3
2.5
2
1.5
1
0.5
0
Full
Mild
NYCC
Jap10.15
FTP
CAFÉ
US06
HWY
REP5
Driving cycle
Predicted Hourly Fuel Savings by Switching from a Conventional Vehicle to Hybrid, by Driving Cycle
From Argonne Hybrid Electric Vehicle Technology Assessment, 2001
16

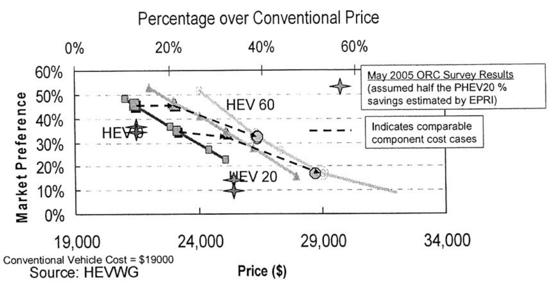

U.S. Average Electric Rates Imply Considerable Per Mile Savings for PHEV20 Electricity Use at Present Gasoline Prices
~ $3.00/gallon in April 2006
U.S. gasoline prices
~ $2.25/gallon in April 2005
U.S. average price, 2005
Off-peak price range
On-peak price range
1990s U.S. Annual Price Range
Dollars per Mile
0.090
0.075
0.060
0.045
0.030
0.015
0.000
$3.25 $2.75 $2.25 $1.75 $1.25 $0.75
Dollars Per Gallon
17 14 11 8 5 2
Residential Cents per kWH
On-Road Fuel Costs Per Mile - EPRI Mid-Size HEV20 on Gasoline or Electricity, City Cycle (UDDS)
(HEV20 is a plug-in hybrid with 20 miles of AE range, 0.4 kWh/mi assumed [higher than EPRI study])
17


Charging PHEV60s Would Push Non-Vehicle Customer Costs Up Considerably, Due to Needed Rewiring to Allow Faster Charging to Stay in an Off-Peak Time Window
PHEV60 w 120V, 20A
PHEV60 w 120V, 15A
PHEV20 w 120V, 20A
PHEV20 w 120V, 15A
$350 Cable + Wiring
$80 Cable
$350 Cable + Wiring
$80 Cable
Large SUV
Mid Size SUV
Mid-Size Car
Compact Car
0.0 5.0 10.0 15.0 20.0 25.0
Hours of "off peak" power?
Hours to Charge
EPRI HEV Studies' Estimates
Source: EPRI 1006892, 2002 and 1000349, 2001
18


Considering EPRI HEV Type Market Share Estimates, Which PHEV Would Save Most Oil?
Mean gallons used per vehicle per 100 miles - fleet of 1000
Note: If the battery must be replaced in the PHEV20 and not the PHEV60, the PHEV60 is best
Gallons
4000
3000
2000
1000
0
Is this the type of PHEV that results in a minimum?
Or is the low point elsewhere?
0% HEV; 100% CV
35% HEV 65% CV
34% PHEV20; 66% CV
17% PHEV20; 83% CV
CV
HEV0
PHEV20
PHEV60
Mid-size car – HEV powertrain paired against the conventional (no other HEV competitor)
Source: EPRI 1000349, 2001
19


As Powertrain (Battery!) Costs Drop, Share of All HEVs Rises. For Long Commutes, Low Costs, PHEV60s Close the Gap & Compete
Share of Market
60%
50%
40%
30%
20%
10%
0%
HEV0
HEV20
HEV60
Low
Base
High
Cost of Vehicle
> 15 mile commute case
20

EPRI Survey Results Imply Significant Increase in Share if Research Leads to Declining PHEV Incremental Costs. Markets Exist Even at High Costs



Base Conventional Vehicle Cost = $19000
Source: HEVWG

Each line represents market potential versus price for a simple market in 2010 where HEV 0 and conventional models are available in each mid-size model, or HEV 20 and conventional models compete. The six points on each line are calculated with a common methodology. The two enlarged points on each line show the base case range (before government or automaker incentives). The base case range assumes costs using 100,000 HEVs per year and also reflect different methods of estimating the retail price estimate.

Base slide courtesy of D. Taylor, Southern California Edison 21

Summary on PHEV Range and Market Opportunities

- Half of U.S. households have daily mileage under 30 mi.
- For these customers, at costs used, NREL cost effectiveness analysis implies PHEV40s and PHEV60s would have a net cost, while PHEV10s and PHEV20s have net benefits.
- EPRI consumer preferences analysis indicated a subset of urban drivers with short commutes, with total driving averaging ~ 20 mi/day, have greatest interest in PHEV20s over HEVs, and consistently prefer PHEV20s over PHEV60s, regardless of price.
- The EPRI survey also indicates that if less expensive batteries and PHEV powertrains emerge from R&D, a significant expansion of the market for longer range PHEVs could be realized among long range commuters.
- For long range commuters, in the EPRI low powertrain cost case, PHEV60s were as likely to be chosen as PHEV20s.

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A Sequence of Announcements: Interest in a Plug-in Feature for Hybrids is Emerging Jointly with the Lithium Ion Battery in HEVs

- 2000 DOE Shifts Battery R&D to Li-ion for Advanced Hybrids and Hybrid FCVs
- 2001 EPRI and Argonne Publish PHEV Analyses Based on NiMH
- DaimlerChrysler Diesel PHEV Sprinter Vans (9/04) (initial plans for NiMH, Li-ion now preferred)
- Turning the Prius into a Plug-in Hybrid (12/04) (initial experiments with PbA)
- Commercial Retrofit for Plug-in Prius by E-Drive Using Li-ion Pack (5/05)
- Hymotion Unveils Plug-in Hybrid Kits for Toyota and Ford Hybrids, Both Using Li-ion Packs (2/06)
- SAAB Unveils E100 Hybrid (show car with 6-12 mi. electric range if < 31 mph and if li-ion battery pack is used) 3/06
- Mitsubishi Fuso Shows Medium Duty Hybrid Cabover Work Truck in U.S. 4/06
  - (not a plug-in, but with li-ion battery pack)

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Fundamental Question:

What is the hybrid battery chemistry of the future?

Nickel metal hydride

Lithium ion

Is that also the plug-in hybrid battery chemistry of the future?

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Many Questions and Technology Options Were Not Previously Examined

- **Items not addressed in the 2001 studies**
  - **Li-ion batteries**
  - **Desirability of a wide spectrum of electric ranges**
  - **Varying electric operations capabilities – top speed, acceleration rate**
  - **Effects of highly variable, often wide SOC swings on battery power/life**
  - **Multiple HEV powertrain configurations**
  - **In-use vs. certification cycle fuel economy**
  - Incremental cost/benefit evaluations
  - Charge depletion w/o EV only operation
  - Towing requirement effects
  - Isolation of HEV vs. PHEV incremental benefit/cost
  - Urban vs. non-urban & morning vs. other emissions
  - New studies indicate U.S. trips are shorter than assumed

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The Balance of Engine and Battery (or Motor) Power for PHEVs Could Vary Significantly, Depending on Performance Specifications, Design Strategy, Customer Needs

Selected statistics from some PHEV simulations – 2000-2006

Parameter Electric range (mi.) Date prepared	Camry 0 2006	EPRI 0 2000	Argonne 7.5 2006	Argonne 10 2006	EPRI 20 2000	Argonne 30 2006	NREL 40 2006	Argonne 50 2006	EPRI 60 2000
Engine Power (kW)	110	67	75	75	61	76	82	83	38
Motor Power (kW)	105	44	40	40	51	41	48	45	75
Battery Power (kW)	30	49	50	60	54	50	52	100	99
Battery (kWh)	1.8	2.9	2.5	3.5	5.9	9.5	18.5	16	17.9
Vehicle Mass (kg)	1669	1603	1609	1610	1651	1665	1703	1843	1767
Peak EV mph	30s	>80	>55	>55	>80	>55	>80	>55	>80

Note: Recently prepared Argonne examples are selected from the "low tech" cases
EPRI cases are from the conventional mid-size glider case, not the low load vehicle
All cases are for a mid-size passenger car

Courtesy of A. Rousseau, Argonne, T. Markel, NREL, EPRI 1000349 and Toyota.com

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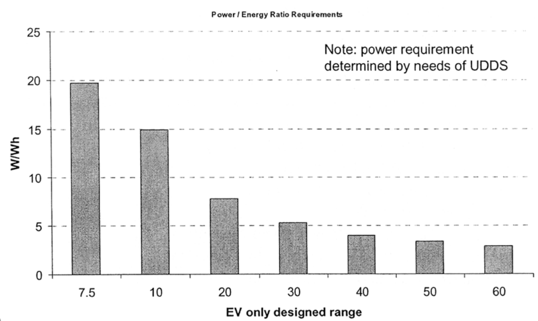
As the Range of PHEVs Rises, the Needed Battery Power to Energy Ratio Declines.

(This reduces $/kWh costs [not shown])



Source: PSAT simulations courtesy of A. Rousseau, Argonne

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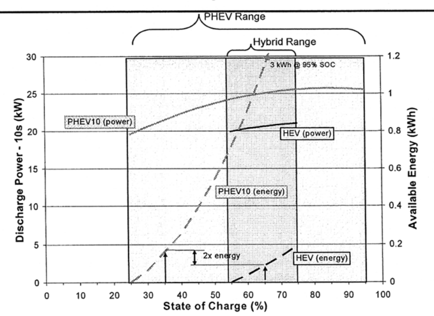
The Ability to Pull Electricity From a Battery to Move a Vehicle is Related to Power. Below Demanded Power, Less Power = More Time to Use a kWh. Battery Power Drops with DOD



Example: PHEV10 vs. HEV0, Li-ion pack simulation

Source: Plug-in HEVs: A Near-Term Option to Reduce Petroleum Consumption. T. Markel et al. NREL 05 Milestone Report, Jan., 19, 2006

Source: T. Markel, NREL

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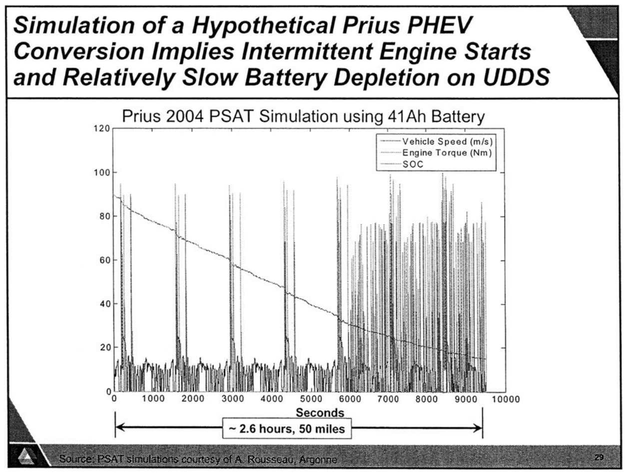
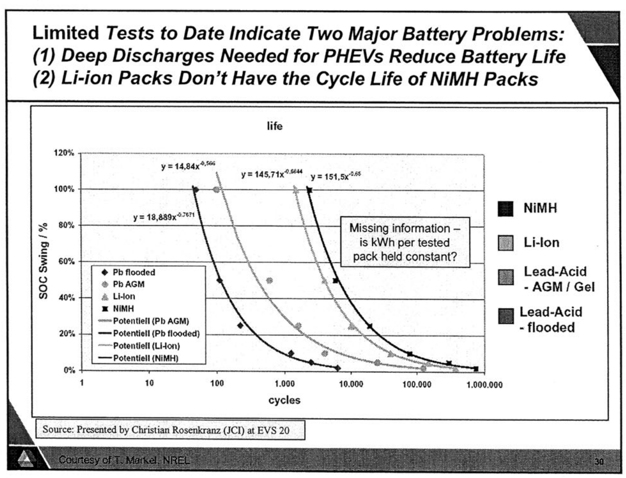
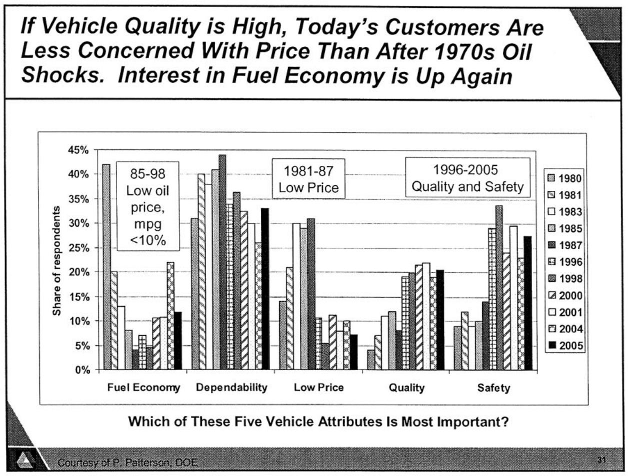
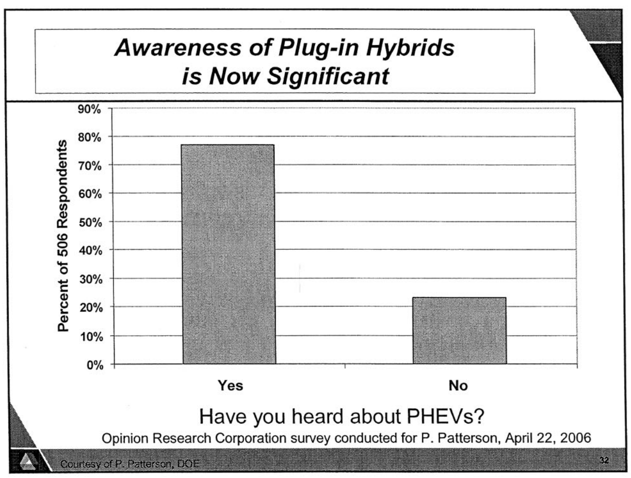
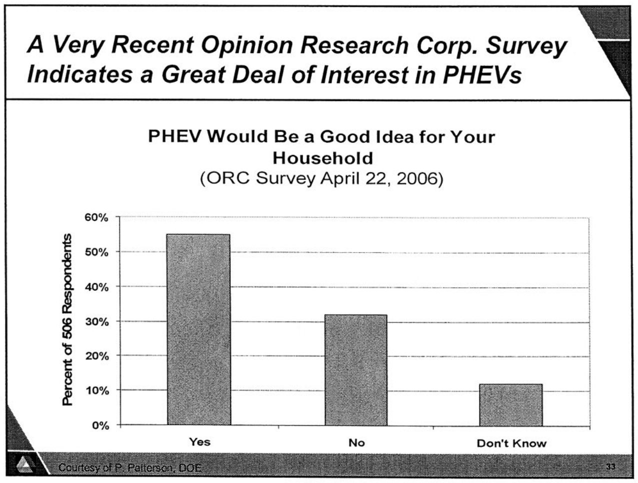
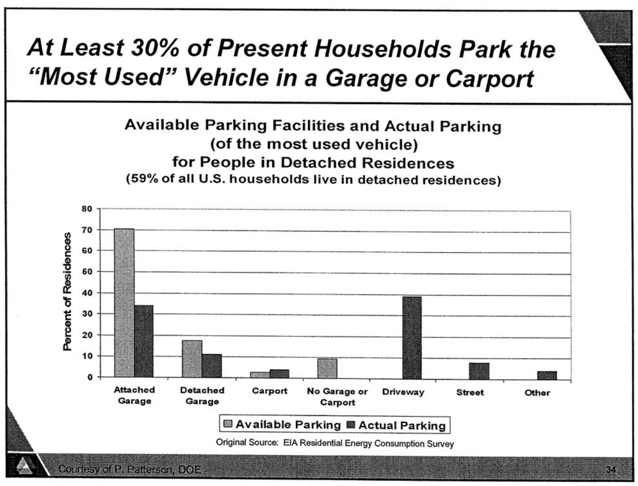

Simulation of a Hypothetical Prius PHEV Conversion Implies Intermittent Engine Starts and Relatively Slow Battery Depletion on UDDS
Prius 2004 PSAT Simulation using 41Ah Battery
Vehicle Speed (m/s)
Engine Torque (Nm)
SOC
Seconds
~ 2.6 hours, 50 miles
Source: PSAT simulations courtesy of A. Rousseau, Argonne


Limited Tests to Date Indicate Two Major Battery Problems:
(1) Deep Discharges Needed for PHEVs Reduce Battery Life
(2) Li-ion Packs Don't Have the Cycle Life of NiMH Packs
life
y = 14,84x-0,566
y = 145,71x-0,6644
y = 151,5x-0,65
y = 18,889x-0,7671
Missing information – is kWh per tested pack held constant?
SOC Swing / %
Pb flooded
Pb AGM
Li-Ion
NiMH
Potentiell (Pb AGM)
Potentiell (Pb flooded)
Potentiell (Li-Ion)
Potentiell (NiMH)
cycles
NiMH
Li-Ion
Lead-Acid - AGM / Gel
Lead-Acid - flooded
Source: Presented by Christian Rosenkranz (JCI) at EVS 20
Courtesy of T. Markel, NREL


If Vehicle Quality is High, Today's Customers Are Less Concerned With Price Than After 1970s Oil Shocks. Interest in Fuel Economy is Up Again
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Share of respondents
85-98 Low oil price, mpg <10%
1981-87 Low Price
1996-2005 Quality and Safety
1980
1981
1983
1985
1987
1996
1998
2000
2001
2004
2005
Fuel Economy
Dependability
Low Price
Quality
Safety
Which of These Five Vehicle Attributes Is Most Important?
Courtesy of P. Patterson, DOE
31


Awareness of Plug-in Hybrids is Now Significant
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of 506 Respondents
Yes
No
Have you heard about PHEVs?
Opinion Research Corporation survey conducted for P. Patterson, April 22, 2006
Courtesy of P. Patterson, DOE
32


A Very Recent Opinion Research Corp. Survey Indicates a Great Deal of Interest in PHEVs
PHEV Would Be a Good Idea for Your Household
(ORC Survey April 22, 2006)
Percent of 506 Respondents
60%
50%
40%
30%
20%
10%
0%
Yes
No
Don't Know
Courtesy of P. Patterson, DOE
33


At Least 30% of Present Households Park the "Most Used" Vehicle in a Garage or Carport
Available Parking Facilities and Actual Parking
(of the most used vehicle)
for People in Detached Residences
(59% of all U.S. households live in detached residences)
Percent of Residences
80
70
60
50
40
30
20
10
0
Attached Garage
Detached Garage
Carport
No Garage or Carport
Driveway
Street
Other
Available Parking
Actual Parking
Original Source: EIA Residential Energy Consumption Survey
Courtesy of P. Patterson, DOE
34

Will Desire for Features Other Than Reduced Fuel Cost be Important?

How badly do customers want various attributes?

- Gasoline savings
- Reduced trips to gasoline stations
- Emissions reductions
- Power back-up
- Emergency transport capabilities
- All-electric operations capability

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Can the Market Share Assumptions Made in the National Lab Scenarios be Achieved? Which Questions Below Are The Most Important to PHEV Market Success? Which Others?

- Will oil prices stay near current levels or above in coming decades?
- Will carbon taxes be imposed over the time horizon under consideration?
- Will fear of international turmoil create an incentive for electricity as a back-up?
- Will hybrid powertrains capture a large share of the market?
- Are PHEVs likely to capture a significant share of the hybrid market?
- How will market share differ as a function of electric range capability?
- Can li-ion batteries be made for as little \$/kWh and \$/kW as nickel metal hydride?
- Can safety concerns with li-ion be successfully addressed?
- Can variations in battery performance as a function of temperature be reduced?
- What is the long-run value of packaging benefits of li-ion packs vs. nickel metal hydride, relative to savings of vehicle glider cost?
- Will technological improvements in batteries push costs down more than demand for battery materials pushes battery cost up?
- Will complex battery SOC management strategies be needed and cause market share to be limited to a group of enthusiasts and/or highly educated users?
- Will batteries last the life of vehicles? Do they need to?
- Can secondary uses/recycling make battery value high at end of life in the PHEV?

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Conclusions

None, it is too early to draw conclusions -

except - there is a lot to discuss in the breakout sessions

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National Campaign

Plug-In Hybrid Electric Vehicles (PHEVs)

Plug-In Partners National Campaign

Building a Market for Gas-Optional Flexible-Fuel Hybrids

Plug-In Hybrid Electric Vehicles: The near-term solution

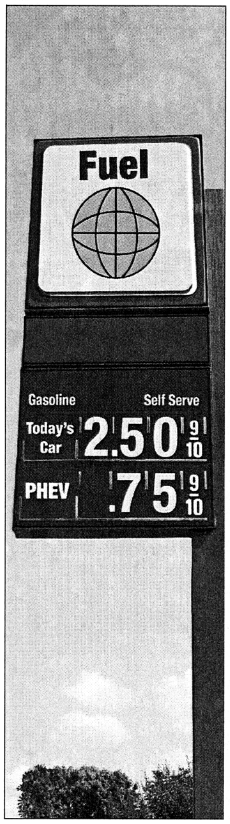
- Plug-in hybrid electric vehicles (PHEVs) can dramatically decrease American dependence on imported oil, reduce greenhouse gases and other air pollutants, as well as lower fuel costs for American consumers.
- PHEVs use the same technology as the popular hybrids on the road today, but have a more powerful battery that can be recharged in a standard home outlet.
- PHEVs are outfitted with a battery pack sufficient to power the vehicle from 20 to 60 miles on battery charge alone.
- Since half the cars on America's roads are driven 25 miles a day or less, a plug-in with a 25-mile range battery could eliminate gasoline use in the daily commute of millions of Americans.
- PHEV technology is already available and functioning. DaimlerChrysler has developed and is testing a prototype PHEV commercial van with a 20-mile all-electric range. Conversions of existing hybrids ranging from sedans to SUVs are on the road today, demonstrating that the technology works.
- PHEVs can be manufactured with flexible fuel engines, magnifying the economic, environmental and security benefits while also benefiting American agriculture.
- An "electric" equivalent gallon of gas will cost 70-80 cents at prevailing electric rates versus the $2.00+ national average gasoline price.
- The electric infrastructure is in place and available. Over 40% of the generating capacity in the U.S. sits idle or operates at a reduced load overnight when most PHEVs would be recharged. Our power system could charge tens of millions of PHEVs without requiring new plants.

Fight for American Independence

PHEVs can:

- **Reduce dependence on foreign oil**
- **Decrease greenhouse gas emissions for vehicles**
- **Lower fuel costs**
- **Make American agriculture a fuel source**
- **Save and create American jobs**
- **Increase use of renewable energy**

Plug-In Hybrid Electric Cars Enjoy Broad Support



"If by 2025, all cars on the road are hybrids and half are plug-in hybrids, U.S. oil imports would drop by 8 million barrels per day (mbd). Today, the United States imports 10 mbd and is projected to import almost 20 mbd by 2025."

— ***Set America Free initiative, a coalition of prominent individuals and non-profit organizations concerned about the security and economic implications of America's growing dependence on foreign oil***

"Plug-in Hybrid Vehicles allow us to use made-in-the-USA energy for most of our driving, breaking the yoke of our dependence on oil."

— ***Institute for Analysis of Global Security***

"In fact, thanks to the existing grid's excess capacity at night, it should be possible to support up to 30 percent of the nation's vehicles equipped with plug-in batteries of 20-mile range and not have to expand electricity generation."

— ***Frank Gaffney, President, Center for National Security Policy***

"When you consider that 78 percent of Americans live within 20 miles of their jobs, and that most car trips — commuting, shopping and dropping off the kids at soccer games — are less than 20 miles, plug-in hybrids could run solely on electricity for these types of short trips and commutes."

— ***Consumer Reports***

"Our studies show a strong market preference for plug-in hybrid vehicles when performance is equal and the cost difference is reasonable."

— ***Bob Graham, Area Manager, Transportation, EPRI***

"We think the transportation fuel sector should be diversified by utilizing more electricity as a fuel (for) plug-in hybrids that can get 100 miles per gallon and allow you to run on electricity alone for 20 to 30 miles, then shift to the combustion engine."

— ***Gal Luft, Director of the Institute for the Analysis of Global Security, an energy-security think tank in Washington***

"We believe that the 50 largest cities in this country, united in purpose, can build a groundswell of demand sufficient to entice carmakers to mass produce what is the logical near term response towards the critical goal of energy independence. We intend to set the example in Austin, TX."

— ***Will Wynn, Mayor of Austin, Texas***

Building a Market for a Flexible-Fuel PHEV

Plug-In Partners is a national grass-roots campaign to demonstrate that a market exists right now for flexible-fuel Plug-In Hybrid Electric Vehicles (PHEVs).

Key components of the campaign include rebates and incentives, "soft" fleet orders, petitions and endorsements. Partners in this campaign are local and state governments, utilities, and environmental, consumer and business organizations.

The "Plug-in Partners" national campaign kicked-off on January 24, 2006. Cities and organizations across America are invited to use this identifying logo, and launch a Plug-In (name of City) campaign for their locale.

Rebates and Incentives

Rebates and incentives could be provided through various sources, including electric utilities — a logical source, since the industry stands to receive additional revenues if PHEVs achieve significant market penetration.

Austin Energy, the city of Austin's public electric utility, has set aside $1 million for rebates for Austin Energy customers when PHEVs become available. Rebates or incentives could also be provided by businesses or organizations to their employees, perhaps as a match to a utility rebate or tax incentive.

Fleet Orders

Advance orders of PHEVs for future fleet needs are an important component of the campaign. These "soft" fleet commitments state that a business or government will seriously consider purchase of PHEVs if the vehicles are manufactured. The fleet orders will demonstrate a demand to automakers.

Petitions

The collection of signatures will allow a large number of Americans to speak directly to automakers. The petition used by Austin simply states that the signer understands what plug-ins are, and that they will seriously consider buying such a vehicle if it is manufactured. Petitions can be signed online at **www.pluginpartners.org**

Endorsements

Endorsements demonstrate organizational support for plug-ins in the form of a City Council or County Court resolution, a legislative resolution, or a statement of support from a local or national environmental, consumer, civic, or other organization. When an organization endorses the Plug-In Partners campaign, it is voicing its support for the mass production of PHEVs and will promote plug-ins to its membership.

Press Event

Hold a press conference to announce your PHEV initiative and your participation in the Plug-in Partners National initiative.

Available Tools

To assist in the development of Plug-In (name of City) campaigns, the following can be downloaded at **www.pluginpartners.org**:

- Sample City Council and County Court resolutions
- Sample "soft" fleet order form
- Petition for the collection of signatures
- Letters of invitation seeking participation by environmental and business groups
- Plug-In logo and this Plug-In Partners brochure
- Links to a variety of resources.

Frequently asked Questions about Plug-In Hybrid Electric Vehicles (PHEV)

Are PHEVs available today?

There are no commercially available PHEVs today, but there are prototypes in operation. DaimlerChrysler has developed and is testing a plug-in Sprinter Van prototype with an all-electric range of 20 miles. There are also many conventional hybrids, from sedans to SUVs, that have been converted to plug-ins. Some are getting up to 60 all-electric miles per charge.

Does plug-in technology work?

Yes. This has been clearly demonstrated by several sedan and SUV conversions at the Hybrid Center at the University of California at Davis. A California non-profit, California Cars, modified a Prius by adding a 2.4 kWh lead-acid pack to prove that it could be done. Then, an R&D company, EnergyCS, replaced the standard 1.3 kWh battery pack with a 9 kWh battery pack. The larger battery pack was sufficient to provide half of the power needed to drive the first 60 miles each day. It's like having a second small fuel tank, only you fill this one with electricity at an equivalent cost of under $1 per gallon, depending on your car and your electric rate. You refill at home, from an ordinary 120-volt socket, with energy that's much cleaner and cheaper and not imported.

What is the problem then?

The cost of the batteries needed to power a PHEV a sufficient distance is considered to be the stumbling block. However, battery technology is advancing rapidly and cost is expected to decrease with mass manufacture.

What distance must a commercially produced PHEV be able to achieve on the battery alone?

According to EPRI (Electric Power Research Institute), half the cars on U.S. roads are driven 25 miles a day or less. Consequently, a plug-in with a 25-mile all electric range could eliminate gasoline use in the daily commute of tens of millions of Americans. Furthermore drivers of PHEVs would only need to fill up with fuel a few times a year, versus the current 24-36 times a year on average.

Won't PHEVs just replace air pollution from automobiles with air pollution from power plants?

No. In almost every conceivable power generation mix plug-ins reduce greenhouse gases and other pollutants. Additionally, emissions would be concentrated in one location that is often away from critically-endangered air sheds. Also, it is less difficult to control emissions from a relatively few number of smokestacks rather than millions of vehicle tail pipes. And, efforts to clean up coal plants and other emissions will continue. In recent decades, many power plants have been modified to lower emissions while a number of older plants have been retired. This trend has resulted in a 25% decrease in emissions from U.S. power plants over the last 25 years. This trend is continuing so emissions will continue to get cleaner over time, meaning emissions generated from electric transportation will get cleaner over time. Furthermore, an increasing share of America's electricity is being produced by zero emission sources - wind and solar. There is a synergy between increased use of PHEVs and expanded use of wind energy. Widespread use of PHEVs in an electric system makes it easier for that system to accept more wind energy. This is because most PHEVs will be charging at night, when demand for electricity is at its lowest, and wind energy production tends to be at its highest in many parts of the country. Also, PHEV batteries can act as storage for wind energy produced at off-peak times.

What about performance? Will PHEVs be slow?

No. A Toyota Prius, modified with a larger plug-in battery, has essentially the same accelerating power and speed capability of a current hybrid.

How much more will a PHEV cost versus a comparably sized conventional hybrid?

EPRI estimates that, with mass production, the cost of a PHEV battery will add $2,000 to $3,000 to the cost of a conventional hybrid. EPRI studies project that after considering the lower costs of fuel and maintenance, a mass-produced PHEV should provide better overall economics than either a conventional hybrid or a conventional vehicle.

CONTACT INFORMATION
www.pluginpartners.org

Plug-In Partners
National Campaign

Plug-in Partners:

Plug in Partners National Campaign

(As of May 15, 2006)

Cities

Austin, TX
Arlington, TX
Baltimore, MD
Boston, MA
Boulder, CO
Corpus Christi, TX
Dallas, TX
Denton, TX
Denver, CO
Edmond, OK
Fayetteville, AR
Fort Worth, TX
Irvine, CA
Kansas City, MO
Keene, N.H
Los Angeles, CA
Madison, WI
Memphis, TN
Oakland, CA
Philadelphia, PA
Phoenix, AZ
Salt Lake City, UT
San Francisco, CA
Santa Barbara, CA
Seattle, WA
Wenatchee, WA

Counties and Local Governments

Travis County, TX
Sarasota County, FL
Hennepin, MN
King, WA
Oklahoma County
Port of Chelan County, WA
Austin Community College
Wenatchee Valley Transportation Council
State of Oklahoma Dept. of Commerce
Sacramento Metropolitan Air Quality Management District

Biofuel Organizations

American Corn Growers Association
Soybean Producers of America

Non-Profits

Advanced Energy, NC
American Lung Association, TX
Apollo Alliance
Austin/S.A. Chapter of Assoc. of Energy Engineers
California Electric Transportation Coalition, CA
Citizens for Rideable Communities
Electric Power Research Institute (EPRI)
Electric Auto Association, CA
Energy Industries of Ohio
Institute of Electrical and Energy Engineers (IEEE)
Northeast Sustainable Energy Association, MA
NY State Energy & Research Development Agency
Odyne Corporation, NY
Public Technology Institute, DC
Seattle Electric Vehicle Association
Sun Day Campaign

National/Local Environmental Groups

Alliance to Save Energy
American Council on Renewable Energy (ACORE)
Blue Water Network (Friends of the Earth)
California Cars Initiative
Clean Air Coalition, TX
Clean Air Council, PA
Clean Air Force of Central Texas
Colorado Energy Group
Community Clean Water Institute, CA
Earth Policy Institute
Electric Vehicle Association of Greater DC
Greater Long Island Clean Cities Coalition
Green Strategies, Inc.
Greg Cooke, TX
Institute for Environmental Research and Education
Oregon Environmental Council
Plug-in America
Stella Group, Ltd., DC
Sustainable Dallas
Texas Commission on Environmental
Texas State Energy Conservation Office

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Plug-in Partners:
Plug in Partners National Campaign
(As of May 15, 2006)

National Security Organizations

Set America Free Coalition
Center for American Progress
Institute for the Analysis of Global Security

National Utility Associations

American Public Power Association
Edison Electric Institute

Public Power Utilities

Austin Energy
Memphis Light and Gas
Akron Municipal Utility, OH
Alameda Power & Telecom, CA
American Municipal Power-Ohio
American Samoa Power Authority (Pago Pago, AS)
Anaheim Public Utilities, CA
Arcadia Electric Utility, WI
Arizona Municipal Power User's Association (Phoenix, AZ)
Austin Utilities, MN
Barnesville Municipal Power, MN
Beach City Board of Public Affairs, OH
Benton PUD (Kennewick, WA)
Bowling Green Municipal Utilities, KY
Braintree Electric Light Dept., MA.
Brigham City Corp., UT
Bristol Virginia Utilities
Buffalo Municipal Service, MN
Burbank Water & Power, CA
Cavalier Light & Power Plant, ND
Cedarburg Light & Water Commission, WI
City of Batavia, IL
City of Bentonville, AR
City of Camilla, GA
City of Chanute Utility, KS
City of Columbiana Public Utility, OH
City of Edmond Utility, OK
City of Gunnison Public Utility, CO
City of Holdrege, NE
City of Lake City Electric Utility, MN
City of Lamar Utility, MO
City of Mansfield, GA
City of Mesa Electric Utility, AZ

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(As of May 15, 2006)

City of Naperville Dept. of Public Utilities, IL
City of Riverside Public Utilities, CA
City of Redding Electric Utility, CA
City of Safford, AZ
City of St. Charles Utility, IL
City Utilities of Springfield, MO
Clark Public Utility (Vancouver, WA)
Clarksville Dept. of Electricity, TN
Clintonville Water & Electric Plant, WI
Columbia Power & Water Systems, TN
Concord Municipal Light Plant, MA
Cowlitz County PUD (Longview, WA)
CPS Energy (San Antonio, TX)
Cumberland Municipal Utility, WI
Cuyahoga Falls Electric Dept., OH
Danvers Electric Division, MA
Danville Dept. Utilities, VA
Douglas County PUD (East Wenatchee, WA)
Emerald People's Utility District (Eugene, OR)
Energy Northwest (Richland, WA)
Erwin Utilities, TN
Farmington Electric Utility System, NM
Frankfort Electric & Water Plant Board, KY
Freeport Electric, NY
Garland Power & Light, TX
Great River Energy, MN
Hagerstown Municipal Light Dept., IN
Heber Light & Power Co., UT
Imperial Irrigation District
Independence Light & Power, IA
Indianola Municipal Utilities, IA
Jackson Utilities & Public Works, MO
Kansas City Board of Public Utilities, KS
Kirkwood Electric Department, MO
Klickitat County PUD, Goldendale, WA
Lakeland Electric, FL
Lebanon Utilities, IN
Lewes Board of Public Works, DE
Lewis County PUD (Chehalis, WA)
Lodi Electric, CA
Long Island Power Authority
Los Angeles Department of Water and Power
Loup River Public Power District (Columbus, NE)
Lower Colorado River Authority
Massachusetts Municipal Wholesale Electric Company (Ludlow, MA)
Maquoketa Municipal Electric Utility, IA
McMinnville Electric System, TN
McMinnville Water & Light, OR

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(As of May 15, 2006)

Meade Municipal Plant, KS
Monmouth Power & Light, OR
Murray City Power (Murray, UT)
Nebraska Public Power District (Columbus, NE)
New York Power Authority
Omaha Public Power
Orlando Utilities Commission
Owatonna Public Utilities, OK
Pacific County PUD No. 2 (Raymond, WA)
Paducah Power System, KY
Paris Board of Public Utilities, TN
Pasadena Water & Power, CA
Pend Oreille County PUD (Newport, WA)
Piedmont Municipal Power Agency (Greer, SC)
Princeton Municipal Utility, NJ
Red Cloud Municipal Electric Dept., NE
Rochester Public Utility, MN
Rock Falls Electric Dept., IL
Rock Hill Utilities, SC
Roseville Electric, CA
Sacramento Municipal Utility District
Salt River Project (Phoenix, AZ)
Scottsboro Electric Power Board, AL
Seattle City Light, WA
Shelby Division of Electricity & Telecommunications, OH
Snohomish County PUD (Everett, WA)
Solvay Electric Dept., NY
Southern California Public Power Authority (Pasadena, CA)
Southern Minnesota Municipal Power Agency, MN
Spencerport Electric Dept., NY
Stephen Municipal Utilities, MN
Stoughton Utilities, WI
Tell City Electric Dept., IN
Town of Haxtun, CO
Truckee-Donner PUD (Truckee, CA)
Utilities Plus/CMMPA (Blue Earth, MN)
Vermont Public Power Supply Authority, Waterbury Center
Village of Paw Paw (Paw Paw, MI)
Village of Rouses Point, NY
Wadsworth Electric and Communications, OH
Washington Public Utility District Association (Olympia, WA)
Watertown Municipal Utilities, SD
Waverly Light & Power, IA
Willmar Municipal Utilities Comm., MN
Wisconsin Public Power Inc. (Sun Prairie, WI)

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Veridian Corporation, Ontario, Canada

Businesses

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