Edmund G. Brown, Jr.
Governor

PLUG-IN HYBRID ELECTRIC VEHICLE RESEARCH ROADMAP

PIER FINAL PROJECT REPORT

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Prepared By:
UC Davis Plug-In Hybrid Electric Vehicle Research Center

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End−Use Energy Efficiency
- Energy Innovations Small Grants
- Energy−Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End□Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Plug-In Hybrid Electric Vehicle Research Roadmap is the final report for the Plug-In Electric Hybrid Vehicle Research Center project (Contract Number 500-02-004, Work Authorization Number UC MR-060) conducted by The Institute of Transportation Studies at UC Davis. The information from this project contributes to PIER's Transportation Program.

For more information about the PIER Program, please visit the Energy Commission's website at http://www.energy.ca.gov/research/.

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Abstract

The *Plug-In Hybrid Electric Vehicle Research Roadmap* will establish priorities for plug-in hybrid electric vehicle research within California and recommend research funding. The *Research Roadmap* begins with examining the current societal trends and policy drivers that are pushing forward plug-in hybrid electric vehicle technology. This examination is followed by a comprehensive analysis of the current and ongoing landscape of plug-in hybrid electric vehicle-related research, development and demonstration efforts in California, around the United States, and the rest of the world. The plug-in hybrid electric vehicle field is a rapidly growing and changing area with many research entities and small companies entering the field in various areas related to plug-in hybrid electric vehicles, such as public charging infrastructure, plug-in hybrid electric vehicle conversions, and battery development and recycling technologies. As such, it is challenging to keep up-to-date with the constantly changing field. After evaluating the ongoing research, a gaps-and-opportunities analysis was completed to find the holes in ongoing research and opportunities where California can have an impact on plug-in hybrid electric vehicle research, development, and demonstration. These opportunities for research are prioritized on a timeline for each of the six primary research areas: vehicle architecture and control systems, batteries, infrastructure impacts, consumer behaviors, codes and standards, and environmental benefits and lifetime costs.

Keywords: Plug-in, hybrid, electric, vehicle, research, roadmap, architecture, battery, infrastructure, consumer, codes, standards, environmental, lifetime

Executive Summary

The State of California has committed to ascertaining if and how plug-in hybrid electric vehicles can help reduce greenhouse gas emissions and oil consumption by California's fleet of 26 million vehicles. Moreover, California has shown interest in whether plug-in hybrid electric vehicles might also improve the operation of California's electric grid through recharging their batteries from the electric grid at night, when power demand is low. There are several ways in which plug-in hybrids and other battery-powered vehicles could be a strategic component of the future power system in California within the contexts of demand management, needed technical improvements to the grid, "smart grid" technologies, and increased renewable sources.

Recently adopted policies are the primary drivers of plug-in hybrid electric vehicles in California. The most important are the Global Warming Solutions Act (Assembly Bill 32, Nùñez, Chapter 488, Statutes of 2006); the State Alternative Fuels Plan (Assembly Bill 1007, Pavley, Chapter 371, Statutes of 2005); and Assembly Bill 118 (Nùñez, Chapter 750, Statutes of 2007) — which created the Alternative and Renewable Fuel and Vehicle Technology Program and the Air Quality Improvement Program. Also, the California Public Utilities Code Section 740.3 encourages development and implementation of electric transportation as part of a business model for California investor-owned utilities. Moreover, the federal government, under President Obama's leadership, has recently made dramatic shifts in its policies to move toward the electrification of transportation. Together these measures initiate, and to some degree frame, a plug-in hybrid electric vehicle research and deployment process for the state.

The commercial deployment of plug-in hybrids is expected to happen over the course of the next decade. This process will be complex, with many steps that involve significant research. Many of these challenges are being taken up by industry, but there are important research opportunities for the State of California to shape and accelerate the deployment. Given its past leadership in controlling vehicle emissions, its important role as a major automotive market, and innovations in the electrical sector, California lead in developing research that bridges the automotive and power sectors.

These research needs and opportunities arise from the unique technical, cost, and behavioral variability presented by a dual-fueled, combustion, and battery-powered vehicle; the technical and systemic challenges, impacts, and opportunities that come with integrating battery-powered vehicles with the state's electrical system; and calculating the benefits of plug-in hybrids to California.

The *Plug-In Hybrid Electric Vehicle Research Roadmap* provides a way for California to find out if and how plug-in hybrid electric vehicles can help it reach its energy and environmental goals. This strategy was developed through research and consultation with many California stakeholders. Plug-in hybrid electric vehicle research opportunities are divided into six research topic areas:

- Plug-in hybrid vehicle architectures and control systems
- Plug-in hybrid batteries
- Plug-in hybrid infrastructure impacts
- Plug-in hybrid consumer behaviors
- Plug-in hybrid codes and standards
- Plug-in hybrid environmental benefits and lifetime costs.

The roadmap includes a comprehensive review of the research needs for plug-in hybrids mapped onto three time frames of future research: near-term: from now until 2012; midterm: from 2012 until 2017; and long-term: from 2017 and beyond. These time frames are taken from the *State Alternative Fuels Plan* and roughly correspond to time frames in the Zero Emission Vehicle program as well as plug-in hybrid electric vehicle commercialization plans from some of the major automakers. The research opportunities below are a synthesis from stakeholder workshops, interviews, and research conducted by the Plug-in Hybrid Electric Vehicle Research Center.

Vehicle Architecture and Control Systems

The drive train architectures of plug-in hybrid electric vehicles include the electric motor, the battery, the power electronics that deliver electricity to the motor, the internal combustion engine, and a range of mechanical devices and computer programs that can split or combine power to the wheels from the internal combustion engine and electric motor systems. There are many ways to integrate these components and therefore many ways to design a plug-in hybrid electric vehicle. Vehicles can vary greatly in the size and design of batteries and engines, emphasizing the electric or gasoline power output over distance or power demand events. Drive trains include power-split drive, parallel, and series designs; control strategies for the "charge depleting" mode include blended and all-electric operation. Vehicle drive-train architecture and control strategy research is conducted mostly by automakers to develop vehicles for consumers and regulatory goals. Their work includes computer simulation programs as well as carefully sequenced laboratory design iterations and real-world testing and measurements. Toyota, Ford, General Motors, and Daimler have all developed proprietary architectures. This tremendous variability and the flexible options they provide to consumers makes for a complex plug-in hybrid design world. Despite a strong proprietary research agenda by the automotive industry, there are areas of interest for the state of California to research.

Drive Train Emissions

California is interested in the development of vehicles, which can reduce greenhouse emissions and integrate best with its electrical system. Each plug-in hybrid electric vehicle architecture (and control system) will have specific emissions implications and needs to be characterized for the energy and greenhouse gas-planning going on in the state. In addition to testing the vehicle power train architectures within computer simulation programs, there are an almost limitless number of possible control strategies that can be implemented in the various power train architectures. In particular, the engine on/off operation inherent in all hybrid electric vehicles can make achieving required emissions levels challenging and poses a prime example of necessary research.

Batteries

Batteries have been the limiting factor in the design, performance and cost of plug-in hybrids and electric vehicles (Anderman 2007). Plug-in hybrid electric vehicle and battery electric vehicle designers have become more optimistic in recent years, given improvements in the performance and the longevity of lithium. However, the cost of such batteries remains too high, casting uncertainty on their success in the market (Axsen 2009). While plug-in hybrids are expected to enter a commercialization trial period around 2011, at present there are no cells, modules, or packs for plug-in hybrid electric vehicles or battery electric vehicles available in the market.

Given the high costs of lithium batteries, there are considerable efforts going into the design of battery manufacturing. Basic battery chemistry research is an expensive and ongoing effort in battery companies, federal energy labs, and universities. Additionally, automobile manufacturers are testing and redesigning batteries for vehicles. Despite such broad existing and emerging research programs on batteries, there are significant research opportunities for automotive traction batteries where state funding can play a decisive and innovative role, particularly in integrating the use of traction batteries across the automotive and energy sectors, widening the market, and creating new values for California vehicle users and ratepayers. The following are the most promising opportunities in which the State might invest:

Second Life Applications

Although vehicle batteries are "spent" when they drop to 70-80 percent of their power capabilities, such batteries will have significant life in other applications. It may be possible to repurpose spent vehicle batteries in second life applications, stretching their value and extending their life. In particular, utilities must develop electricity storage capabilities for intermittent renewables, particularly nighttime wind power, and find ways to offset added capacity needs for increasing peak power needs due to growing air-conditioning loads. The utilities may find value for repurposed spent vehicle batteries as storage devices for nighttime power from renewables and delivery devices for peak needs, especially if such devices help to avoid building new power plants.

Complementary Applications

Vehicle batteries have specific design criteria and control strategies for recharging and use depending on their application. However, there may be other complementary applications with similar designs demands that could expand the market and thus push down costs. There has been previous research in this area on nickel-metal-hydride (NiMH) and lead acid batteries (Cready 2003). Such analysis should be updated to include lithium chemistries, details of the design specifications for each application, and an assessment of the value relative to lithium battery costs.

Cradle-to-Grave Lifecycle Analysis

Batteries will need to be recycled, and their full life energy, mining, manufacturing, and disposal impacts should be considered. Research is needed to discover the full cost of disposal in the life costs of the material and the potential ways to reuse battery materials. At each stage/volume of production, it will be useful for the state to know the lifetime costs so as to inform environmental and energy use models and market expectations.

Testing Protocols

Given its own goals in emissions and energy, the State of California also needs to conduct ongoing benchmarking of the performance of lithium plug-in hybrid batteries including voltages, resistances, cycle life, calendar life, and costs.

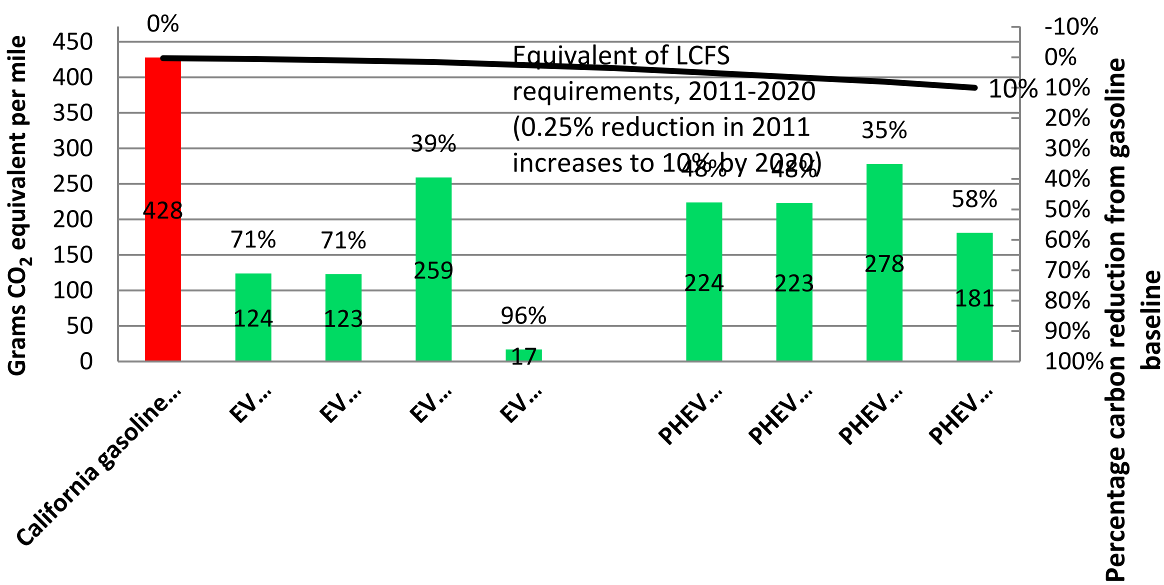


Figure 1-1: Emissions for Electric Vehicles and Plug-In Hybrids by Electricity Source (grams CO_2 equivalent per mile traveled)

Infrastructure Impacts

Recent studies by the Electric Power Research Institute, Pacific Northwest National Laboratories, and American Council for an Energy Efficient Economy (Duvall and Knipping 2008, Knipping and Duvall, 2008, Kintner-Meyer et al. 2007, Kliesch and Langer 2006) have concluded that utilities have enough nighttime generation capacity to charge significant numbers of plug-in hybrids. However, capacity problems would emerge if consumers charge during peak hours. The primary problem for infrastructure is not capacity, but designing this new system so that vehicles are charged at the right time and with proper controls to enable a greener, more efficient, and affordable power system. In particular, as California adds renewable energy sources, wind and solar, to its future power system, charging of vehicles becomes a system factor. The time, location, and cumulative power demands of plug-in hybrid electric vehicles plugging into the grid can help or hinder this greening of the grid. Nevertheless, California will want to develop a charging system that is attractive and practical for plug-in hybrid buyers and users. Additionally, given the high costs of transitioning to electric vehicles, this infrastructure must be affordable.

Throughout the world, many plans are developing for electrical charging networks to encourage the plug-in hybrid electric vehicle and battery electric vehicle market. A number of firms, including Better Place and Coulomb Technologies, are designing whole systems for public charging of plug-in hybrid electric vehicles and battery electric vehicles, with frequent charging stations (two per vehicle and more), fast-charging, and even battery-swapping facilities. These systems are expensive, and there are no evaluation or planning tools to help city or utility planners, or other stakeholders, determine if such systems are essential to build the market. Furthermore, there are no tools to help predict the impacts of charging on the local grid infrastructure as the number of plug-in electric vehicles grows, particularly when the market develops in localized clusters of owners.

Design and Rollout of the Public and Private Charging Network

Compared to pure battery vehicles, plug-in hybrids can charge in a reasonable period through less expensive charging opportunities-such as 120 volt, 15-20 amp circuits, given their smaller batteries. However, even the basic 120 volt opportunities do not exist for all car buyers. Near-term research should explore whether the existing 120 volt charging infrastructure will be attractive and sufficient for plug-in hybrid electric vehicle consumers, evaluating their satisfaction with cost, availability, and speed of charging. Additionally, will lack of infrastructure for potential buyers inhibit market growth?

Time-of-Use Controls and Interfaces

There are near-term research needs to study the effectiveness of a variety of special time-of-use rates, smart meters, vehicle interfaces, and other devices designed to encourage charging at off-peak hours. In particular, there will be a need to explore how responsive plug-in hybrid drivers will be to "off-peak" charging costs. For example, will rates like $.34 per kilowatt-hour be high enough to discourage on-peak charging? Will businesses and other locations that might offer opportunity charging be discouraged at such rates? Will discouraging on-peak charging adversely affect the market for plug-in hybrids? Plug-in hybrid electric vehicle demonstration projects may be the only context in which to observe responses to these and similar contingencies.

Vehicle to Home and Grid

There has been significant research in recent years about the possible benefits of plug-in hybrids in supplying emergency backup power, or “vehicle-to-home” (V2H) or “vehicle-to-grid” (V2G) connectivity in the future. V2H and emergency backup use of plug-in hybrids present near-term research opportunities while V2G is a longer-term interest due to complexities in the grid's ability to accept such distributed sources. V2G may come about in the long-term but is not necessary for the success of plug-in hybrid electric vehicles, nor would it provide significant benefits for consumers or utility operations until plug-in hybrids are in widespread operation to act in a large controllable distributed-generation capacity for the electrical grid. These applications could present potential market values as well as systems benefits to the grid.

Mobile Electricity

Mobile electricity is using batteries and charge connections to power heating, ventilation, air conditioning systems, or other accessory loads in parked vehicles, or using the parked vehicle to power local power needs (like a campground). This is a long-term research need and could impact energy use calculations for plug-in hybrid electric vehicles and battery electric vehicles if consumers find them compelling.

Consumer Behavior

Recently, Toyota representatives commented that their biggest remaining concern about plug-in hybrids is the cost of the vehicle and therefore potential demand. They estimate that a plug-in hybrid will cost $5000 to $10,000 more than a conventional hybrid. Nevertheless, plug-in hybrid electric vehicle technology might have greater appeal due to their lower fueling costs, fueling flexibility, mobile electricity options, and environmental and fuel security benefits. Research in this area is complex and often done only by automakers. However, the State of California wants to create a plan to encourage the transition to electric vehicles.

This research intersects with previous research discussed above, including consumer response to the cost of batteries, the design and extent of a recharging network, and time-of-day electric rates.

Consumer Willingness to Pay, Adopt, and So Forth

At the present, car owners are accustomed to gasoline and diesel cost of ownership and features of those vehicles. Given the expected high price of plug-in hybrid electric vehicles, it will be important to develop better methods of simulating plug-in hybrid electric vehicle markets to study what prices consumer will pay for various types of plug-in hybrids.

Social Feedback to Consumers (Websites of Users)

Another aspect of the commercialization of plug-in hybrids will be the development of "pioneer" communities, that is early adopters, and especially websites devoted to the plug-in hybrid driver community. Research is needed that both experiments with adopter network effects and interacts with the broader car buying community.

Consumers and Advance Energy Instrumentation

Plug-in hybrid electric vehicles are unique in terms of their dual fuel use, energy characteristics, and variable benefits according to consumer use patterns (EPRI 1998). Essential to understanding potential benefits of plug-in hybrid electric vehicles will be to study consumer response to "advanced energy instrumentation" for plug-in hybrids. Such instrumentation will entail real-time electricity and liquid fuel consumption, costs and accumulated cost, and energy use feedback to the driver. Not only does such instrumentation affect use patterns, such as charging and driver behavior, but feedback from the instruments becomes part of the value proposition of the vehicles. Research should both create such instruments, test these instruments, and test consumer response to such instruments.

Codes and Standards

The United States Department of Energy (DOE), the Environmental Protection Agency (EPA), the Society of Automotive Engineers, and the California Air Resource Board are all developing various codes and standards for plug-in hybrid electric vehicles, including safety, charging, emissions, and fuel economy (Bohn 2009). The Society of Automotive Engineers is developing these codes, for example, to ensure safe and common plug designs (SAE J1772). Another example is how the EPA is determining a procedure for determining the fuel economy of a plug-in hybrid electric vehicle, which would be unique to plug-in hybrids (Gondor and Simpson 2007). Determining the fuel economy and therefore carbon-dioxide-equivalent emissions, of a particular plug-in hybrid electric vehicle will vary according to the local grid mix as well as the vehicle owner's use patterns. California has particular interest to understand just how plug-in hybrids emissions will vary given its grid. Already, General Motors and the EPA have fought over the EPA using the previous hybrid electric vehicle methods to rate the fuel economy of its new Volt extended-range electric vehicle — a type of plug-in hybrid electric vehicle (Goodwin 2008). The current hybrid vehicle test does not credit the Volt with its electricity-only mode. In Europe, regulators at the European Commission have suggested two ratings, one for fuel economy while the battery is discharging, and one after the battery is discharged and the vehicle has reverted to normal hybrid mode.

Energy Use Units

Plug-in hybrid electric vehicle commercialization will need consistent and accurate units of measurement for plug-in hybrids energy use other than the traditional miles per gallon, such as grams or carbon-dioxide equivalent per mile or energy used per mile. This research must be multidisciplinary, as it is not just an engineering issue, but an issue of consumer needs. Researchers must find measurements that communicate with drivers and provide a solid base for comparing plug-in hybrid designs in the market and travel patterns of users.

Environmental Benefits and Lifetime Costs

There is much ongoing research in universities in the area of understanding the environmental benefits and lifetime costs of advanced vehicles, including plug-in yybrid Electric Vehicles. The most widely used model of the emissions of such vehicles is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model, developed by Argonne National Laboratory. Argonne National Labs has issued an update of the greenhouse gases model this spring to reflect these plug-in hybrid options (Elgowainy et al 2009). There are additional models that seek to evaluate the emissions of plug-in hybrids, including University of California at Davis' Advanced Vehicle Lifetime Emissions Model developed by Dr. Mark Delucchi.

Updating Models

Each of these emissions models will need to be updated regularly to account for new information about plug-in hybrids as it becomes available. In the future these updates will need to include information on "real-life" consumer driving and charging behavior, the effect of smart meters and a smart grid, various rates of plug-in hybrid electric vehicle adoption in the marketplace, batteries used in second-life applications, and battery recycle-ability, as well as other variables. Because plug-in hybrid electric vehicles, hybrid electric vehicles, and battery electric vehicles represent so many technical possibilities, California should continue to invest in these models to compare the well-to-wheels impact of various plug-in options. These well-to-wheels models are essential for informing California policy and investments that support climate change and energy security legislation already in place.

Unless otherwise noted, all tables and figures are provided by the authors.

1.0 Trends and Drivers

The commercialization of plug-in hybrid electric vehicles (PHEVs) is being driven primarily by the need to reduce greenhouse gas (GHG) emissions and dependence on petroleum. California has been a leader in energy efficiency and solving emissions problems from transportation. However, along with the rest of the world, California is almost entirely reliant on fossil fuels for transportation energy. Growing demand for fossil fuels worldwide combined with the eventual peaking of oil production predicted to occur during the next decades will lead to a steady decline in supply of oil, increasing prices and dependence on the favor of oil producing nations. Additionally, the production of carbon-dioxide (CO_2) equivalent emissions from petroleum-fueled vehicles accounts for about 40% of greenhouse gas emissions in California (See Figure 1–2. California greenhouse gas emissions inventory).

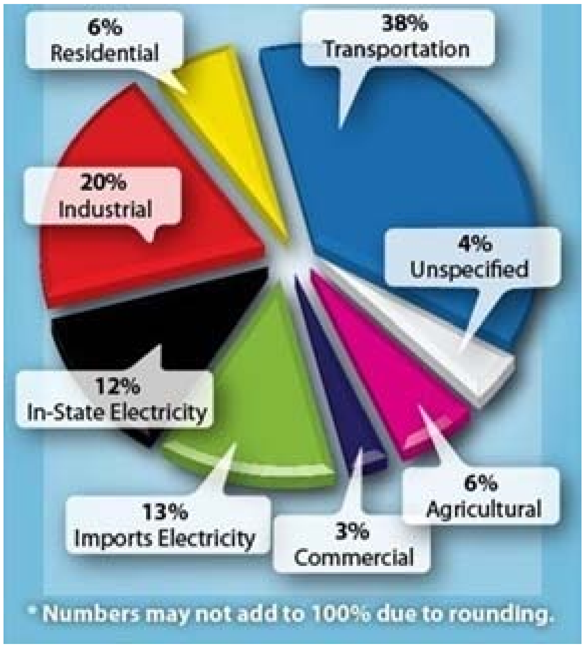


Figure 1–2. California greenhouse gas emissions inventory

Credit: ARB, Nov. 2007

One of the ways to reduce petroleum consumption in California is to use more electricity as a transport fuel. California's electricity system does not use petroleum. It also produces less CO_2 – equivalent emissions per energy unit than petroleum fuels due to its mixed use of natural gas, hydroelectric, renewables, and nuclear. California utilities will produce even less greenhouse gases in the future as they increase the percentage of renewable energy from biofuels, geothermal, wind, and solar. There are a variety of transportation technologies that already run on electricity including trolleys, subways and light rail. However, light-duty vehicles produce the great bulk of transport emissions and therefore greenhouse gas emissions in California. Significant reductions in transport CO_2 will require sizable reductions in the light-duty vehicle sector emissions.

Since the initiation of the Zero Emission Vehicle (ZEV) program in California in the early 1990s, there has been an effort to bring battery electric vehicles to the California market, however, the high price of batteries, limited range and long recharge times halted most original equipment manufacturers (OEMs) commercialization efforts in the 1990s and still limit battery electric vehicles (BEVs) to a niche market and small scale production thus far. However, hybrid electric vehicles (HEVs), which do not "plug-in" to the grid for fuel but do integrate electric motors and batteries into their drive train, have over the past decade grown to about 5% of annual sales in California and 2% nationally (Green Car Congress 2009). A further step in the development of HEVs is the PHEV.

1.1. California Policy Drivers

California continues to lead in developing policy for and funding the advancement of PHEV technology. The Energy Commission's *2005 Integrated Energy Policy Report (IEPR)* instructs the Energy Commission to "engage stakeholders to investigate how investor owned utilities can best develop the equipment and infrastructure to fuel electric and natural gas vehicles." The *2005 IEPR* continues on to say "The state can pursue other strategies to increase transportation efficiency, including increasing the number of hybrid electric, plug-in hybrid and light-duty diesel vehicles in California" (California Energy Commission 2005). It further explains the plug-in hybrid technology and says "…because plug-in hybrids have substantial zero-emission range, they can produce significant reductions in petroleum, criteria pollutants, and greenhouse gas emissions – much more than the very efficient hybrid vehicles available today" (California Energy Commission 2005).

The *2007 IEPR* (California Energy Commission 2007) states "Over the longer term, advanced biofuels, hydrogen, and plug-in hybrid vehicles are expected to play a role in meeting California's Low Carbon Fuel Standard (LCFS)". The *2007 IEPR* (California Energy Commission 2007) also recommends that the state "integrate distribution planning with other resource procurement processes to support the use of new low carbon resources and application – renewables, demand response, efficient combined heat and power, distributed generation, energy storage, advanced metering infrastructure, and Plug-In Hybrid Electric Vehicles".

The Global Warming Solutions Act of 2006 (Assembly Bill 32, Nùñez, Chapter 488, Statutes of 2006) sets the stage for increased interest in electric transportation with greenhouse gas targets for the State. California's LCFS—Executive Order S-1-07—sets a goal of reducing the carbon content of transport fuel by 10%, and while aimed primarily at refineries and fuel producers, using electricity as a transportation fuel is one of the ways toward satisfying the standard.

Transportation plays a large role in California's overall GHG emissions, contributing 38% of the state's total emissions as of 2004, as seen below in the chart from the *2007 IEPR* showing data from the California Air Resources Board (ARB). Plug-in hybrids are seen as a key component in significantly reducing transportation emissions.

The Budget Act of 2006 (Assembly Bill 1811, Laird, Chapter 48, Statutes of 2006) directed ARB to develop a joint plan with the Energy Commission to spend $25 million for the purposes of incentivizing the use and production of alternative fuels, including "grants for research and development of clean and zero emission fuels and vehicle technology to assist in making those technologies affordable in the marketplace." The PHEV Center was chosen to receive $1.5 million in funds for consumer studies of PHEVs.

Assembly Bill 1007 (Pavley, Chapter 371, Statutes of 2005) directs the Energy Commission, in partnership with the ARB, to develop and adopt a *State Alternative Fuels Plan* (SAFP) to: "recommend policies, such as standards, financial incentives, research, and development programs, to stimulate the development of alternative fuel supply, new vehicles and technologies, and fueling stations; to evaluate alternative fuels using a full fuel cycle analysis of emissions of criteria air pollutants, air toxins, greenhouse gases, water pollutants, and other substances that are known to damage human health; and to set goals to increase alternative fuels in 2012, 2017, and 2022 that there is no net material increase in air pollution, known to damage human health." The plan identifies the potential for steady and substantial growth in the use of many alternative fuels, the mix of which will change and evolve over the near term (2007 to 2015), midterm (2016 to 2030), and long term (2031 to 2050).

The SAFP, jointly put forth by the Energy Commission and ARB, called for in AB 1007 and completed in December 2007, includes PHEVs in its analytical scenarios to achieve CO_2 reductions and alternative fuel futures, and sets forth on page 25 a list of desirable "Immediate" Electric Transportation Technology Actions for PHEVs (and EVs). The key PHEV research items identified in the SAFP are:

- Research and develop advanced battery models to improve performance, reduce weight, lower costs, and demonstrate safety for light-duty and heavy-duty vehicles.
- Research and develop ways to integrate new battery charging and recharging profiles into drive cycles for electric drive vehicle models.
- Research and develop projects to integrate PHEV architecture with fuel cell systems.
- Research and develop projects to integrate passenger PHEVs and heavy-duty vehicles with other alternative fuels.

For the complete list of electric transportation technology actions, see the State Alternative Fuels Plan, available on the Energy Commission website:
http://www.energy.ca.gov/2007publications/CEC-600-2007-011/CEC-600-2007-011-CMF.PDF

Assembly Bill 118 (Nùñez, Chapter 750, Statutes of 2007), passed in December 2007, places within the Energy Commission an "Alternative and Renewable Fuel and Transportation and Vehicle Technology Program" and funding mechanisms to implement the SAFP. AB 118 is expected to provide over $200 million per year between the Energy Commission and ARB over 7 years. The Energy Commission is currently developing regulations to move the program forward.

In March 2008 the ARB incorporated PHEVs into its ZEV program. To give greater value to PHEVs, the ARB staff put forth a plan to give PHEVs what are called "Silver-Plus" credits, according to whether they use a "blended" control strategy, the amount of All Electric Range

Equivalent (20, 30, 40 miles)(like the Prius conversions) or according to the amount of "all electric range" (20, 40, 60 miles). On March 27, 2008, the ARB voted to allow for 58,000 Enhanced Advance Technology Partial Zero Emission Vehicles in the ZEV credit program over the 2012-14 time frame.

California Public Utilities Code (CPUC) Section 740.3 encourages development and implementation of electric transportation as part of a business model for California investor owned utilities. Specifically, CPUC 740.3 states that:

(a) The commission, in cooperation with the State Energy Conservation and Development Commission, the State Air Resources Board, air quality management districts and air pollution control districts, regulated electrical and gas corporations, and the motor vehicle industry, shall evaluate and implement policies to promote the development of equipment and infrastructure needed to facilitate the use of electric power and natural gas to fuel low-emission vehicles. Policies to be considered shall include both of the following:

    (1) The sale-for-resale and the rate-basing of low-emission vehicles and supporting equipment such as batteries for electric vehicles and compressor stations for natural gas fueled vehicles.

    (2) The development of statewide standards for electric vehicle charger connections and compressed natural gas vehicle fueling connections, including installation procedures and technical assistance to installers.

(b) The commission shall hold public hearings as part of its effort to evaluate and implement the new policies considered in subdivision (a), and shall provide a progress report to the Legislature by January 30, 1993, and every two years thereafter, concerning policies on rates, equipment, and infrastructure implemented by the commission and other state agencies, federal and local governmental agencies, and private industry to facilitate the use of electric power and natural gas to fuel low-emission vehicles.

(c) The commission's policies authorizing utilities to develop equipment or infrastructure needed for electric-powered and natural gas-fueled low-emission vehicles shall ensure that the costs and expenses of those programs are not passed through to electric or gas ratepayers unless the commission finds and determines that those programs are in the ratepayers' interest. The commission's policies shall also ensure that utilities do not unfairly compete with non-utility enterprises.

This set of laws and statutes direct the Energy Commission, ARB, and other agencies of the State of California to reduce both petroleum use and greenhouse gas emissions in California, to carve out a greater role for electricity as a transportation fuel, and to bring attention to PHEVs. Electricity comprises a small percentage of transport energy use at the present. For electricity to become a significant transport fuel, it will take concerted RD&D efforts to prepare the market and infrastructure for PHEVs and produce marketable vehicles. As this market grows the electricity infrastructure must adapt to the added load of PHEV charging, creating more renewable energy resources, encouraging and incentivizing nighttime charging, discouraging on-peak charging, and eventually managing the charging behavior of millions of PHEV owners in a way that provides additional benefits to energy efficiency in California.

1.2. Federal Policy Drivers

In the past year, the Obama administration has made PHEVs a critical technology in its plans to cut green house gas emissions and reduce oil imports. As a centerpiece to this policy direction, President Obama has set an accumulative goal of 1 million PHEVs sold by 2015 in the United States. Also, in 2009 the federal government enacted a wide variety of legislation to support the research, development, demonstration, and commercial deployment of plug-in hybrid and electric vehicles. Much of this legislation, formerly found in energy policy that did not pass, has been rolled into the economic stimulus funds, also called the American Recovery and Reinvestment Act, which has passed. The following summary is found on the Plug In America website: http://action.pluginamerica.org.

- $2 billion is Grants for advanced battery manufacturing, (House of Representatives [(H.R.)] 1, pg. 24; originally authorized but not funded under the Energy Independence and Security Act of 2007 [(EISA)],-Section 135).
- $2 billion of the $14.4B total is allocated for Plug-in Vehicle Tax Credit (Section 1141 of H.R.1).
    - $2,500 to $7,500, depending on size of battery (4kWh-16 kWh), for electric-drive vehicles (EVs and PHEVs) sold after December 31, 2008. This extends and expands plug-in credits passed with TARP (Troubled Asset Relief Program) in October 2008. The original plug-in tax credits remain in place for 2009, then the new provisions start in 2010 for this part of the credit. The Internal Revenue Service will need to create the actual forms and regulations later this year.
    - The credit was changed from 250,000 vehicles total to 200,000 per automaker. Each automaker will get 100% credit for their first 200,000 vehicles, 50% credit for the next two quarters, and 25% credit for the final two quarters.
    - Sales and leases are both covered.
    - There is no limit to the number of vehicle manufacturers that can qualify for this process.
    - Vehicles larger than 14,000 gross vehicle weight rating are removed after 12/31/09 but may get added back in another piece of legislation.
    - 10% separate consumer tax credit for 2-3-wheeled vehicles (up to $25,000 for a $2500 tax credit). This incentive helps the most affordable and already available vehicles including electric motorcycles (Zero Motorcycles, Vectrix, Brammo, Mission Motors, etc.) and enclosed 3-wheelers like Aptera, Persu Mobility, and

Myers Motors. Vehicles must have a minimum of 2.5 kWh of battery energy. Sunsets December 31, 2011. (H.R.1 - Section 1142)

    - 10% credit for low-speed electrified vehicles (Neighborhood Electric Vehicles), up to $2,500 ($25,000 SRP) until December 31, 2011. (H.R.1-Section 1142)
    - 10% credit for plug-in conversions up to $4,000 ($40,000 conversion value), tax credit also available until December 31, 2011. This applies to both PHEV conversions and internal combustion engine (ICE) to BEV conversions. The Internal Revenue Service will set exact rules.
- $1.7 billion manufacturing tax credit for advanced energy investments up to 30%, including plug-in vehicle manufacture. (H.R.1-Sec 48C)
- $54 million for tax credits on Alternative Refueling Property (including BEV/PHEV charging). They raised the limit from 30% and $30,000 to 50% and $50,000, until 1/1/2011. They also increased the residential refueling property tax credit to 50% of up to $2000 (This is a TARP modification). (H.R.1- Sec 1123)
- $400 million for deployment of plug-in infrastructure and vehicles. (EISA Sec 543B, H.R.1-pg.24).
- $300 million for the federal purchase of commercially available high-efficiency vehicles (including hybrid, plug-in hybrid, and Battery Electric Vehicles) to remain available until September 30, 2011. (H.R.1-pg. 36)
- $300 million to regional deployment of electric drive and alternative fuel vehicles (CleanCities grant support via Department of Energy funding).
- $10 million additional for administration of Advanced Technology Vehicles Manufacturer Loan Program (EISA-2007, H.R.1-Title 17, pg. 26)
- $6 billion additional to Innovative Technology Loan Guarantee program which could go to plug-ins. (authorized under Energy Policy Act of 2005). This program provides loan funding to help automakers retool to make much more fuel efficient vehicles like EVs and PHEVs. (H.R.1-pg. 26) (Plug-in Partners 2009)

In January, 2009, President Obama asked the U.S. Environmental Protection Agency to reconsider the question of whether California and 13 other states could have stricter emissions standards than federal standards (Mufsen and Eilperin 2009). In May 2009, the Obama administration announced that it would propose new standards for tailpipe emissions for vehicles, creating a standard that is strict enough to satisfy California and creating one federal standard across all states (Mufsen, 2009). The new proposal would raise fuel economy standards, and likely will encourage the development of more hybrid and plug-in hybrid vehicles.

1.3. Resource Trends and Drivers

In addition to the many policies and initiatives that are driving the development of PHEVs, there are other drivers that may also be affecting their success. These other trends and drivers include a perceived lack of skilled engineers, increasing costs of source materials for batteries, and a lack of U.S. manufacturing capabilities for lithium-ion (Li-ion) batteries.

Several members of industry have related to the PHEV Center that there is a lack of skilled engineers in key areas of PHEV work such as power electronics, motors, motor controls and utility systems. Establishing US battery manufacturing capabilities would be beneficial to the U.S. economy as well as to the automakers because the shipping costs would be lower than shipping from current battery manufacturers of small format Li-ion batteries in China or Japan. In addition, having the manufacturing in the United States would allow for tighter control of the emissions associated with the battery production process and a better understanding of the battery component of the lifetime well-to-wheel emissions of vehicles. As discussed above, the Obama administration has set aside $2 billion dollars for batter manufacturing in the Federal Economic Recovery Act.

2.0 The Plug-In Electric Vehicle as a System

In this section plug-in hybrid electric vehicles are described in detail regarding the technical characteristics, their potential integration with the electrical infrastructure, their end use by vehicle owners, and their impact on energy use and greenhouse gas emissions in the transport sector. PHEVs, along with BEVs, enable some new system developments related to the storage capabilities of vehicle batteries, the possibility of demand side management of charging, and potential to use of vehicle batteries as temporary storage for renewables in the grid. These energy aspects of PHEVs and BEVs point to a more systemlike approach to the process of electrification of transport. Energy companies, regulators, and vehicle companies will need to engage as partners in a future energy system.

2.1. PHEV Systems

PHEVs are not a single design, but rather a wide range of technical options that combine aspects of Battery Electric Vehicles and Hybrid Electric Vehicles. At the heart of each PHEV design is the integration of three systems:

- Drive-Trains – physically integrate the electric drive and internal combustion power source
- Battery System – emphasizes large or modest energy storage and power capabilities
- Control System – computer programs which instruct the complex relationships between the electric systems and internal combustion systems and manage the battery system.

Much attention is given here to the battery system. Durable and affordable batteries have been the primary challenge for HEVs, BEVs and PHEVs. There are a number of battery chemistries that have been used in the past for BEVs, but the most promising technology for BEVs and PHEVs are lithium batteries. These are currently dominant in the electronic industry for phones, cameras, and laptops; however, the cell size (capacity) needed for vehicles is much larger than that used in consumer electronics. As of today, there are no mass produced lithium cells of the proper size for BEVs or PHEVs, much less readymade modules or packs for PHEVs (Axsen et al. 2008). Battery packs in vehicles are composed of three levels of integration: individual battery cells, which are grouped into modules, then in turn are grouped into battery packs for vehicles. There are no mass-produced cells of the proper size, nor are their available modules or packs.

PHEV battery design must combine aspects of both BEV and HEV batteries. "Full" HEVs have both an internal combustion engine and electric motors that drive the wheels in some capacity ("micro" and "mild" HEVs do not drive the wheels wholly on electric motors). BEVs have only electric motors to drive the wheels and no combustion engine. HEVs are fully reliant on combusted fuels and do not recharge their batteries from the grid, while BEVs are fully reliant on the grid. Full HEVs have much smaller batteries than BEVs, often in the range of 1-2 kWh, that are used to store and deliver electricity to and from the electric motors for short periods, often seconds and minutes. The batteries are "*charge-sustained*" during vehicle operation at a narrow, high state of their charge capacity (usually 60-80%). HEV batteries are optimized for *high power density*, meaning the ability to deliver high power over short periods of time. The battery must be able to endure millions of these shallow cycles over the life of the vehicle. (Axsen et al. 2008)

Pure BEVs have much larger battery packs, determined primarily by the size and the driving range of the vehicle. Typical BEV batteries can range from 15 kWh for city-micro cars to 30 or more kWh for a small sedan with 100 miles of range. BEV batteries are charged from the grid and usually at high power outlets, either Level Two, 220V (for example electric dryer outlets), which can take several hours, or Level Three, which is three-phase (industrial) fast charging that can take 15 to 60 minutes to charge a depleted battery. Electric vehicles are designed to drive a specified range, for example 40-100 miles, until the vehicle battery is depleted and afterwards must be parked and recharged. In technical parlance, BEVs use a *charge-depleting* mode, essentially draining their batteries, usually going from 100% to something like 20%. These are called “deep discharge cycles,” and BEV batteries must be able to endure thousands of such daily or semidaily deep discharges and additional “shallow cycles” over the lifetime of the vehicle. Given that BEVs depend on their battery for all their energy needs, BEV batteries are optimized to hold a lot of electrical energy, what is called high *energy density*, to store the most energy per volume and weight. (Axsen et al. 2008)

PHEV batteries, drive train, and battery control architectures combine both charge depleting and charge sustaining control modes, in that order. PHEVs begin operation at the start of a trip as a charge-depleting vehicle; once the battery reaches a low state of charge, the battery shifts to charge sustaining mode until the driver is parked and recharged. There are also distinct strategies to control the discharge of a PHEV battery during the initial charge-sustaining mode. *Blended* strategies combine electricity and internal combustion power as needed during the charge depleting mode; *series* strategies (like the General Motors [(GM)] Volt) rely only on the battery during the depleting mode, shifting to charge sustaining once the battery reaches a low state of charge at which time the combustion engine is fired up to recharge the batteries. Regardless of these differences, PHEV batteries must: (1) combine attributes of both high energy density batteries for charge depletion (2) at a low state of charge, provide high power density for charge sustaining operation over long distances. PHEV batteries must also sustain more deep discharges in their lifetime than BEVs, as well as millions of shallow discharges. This is a unique demand on batteries and a challenge for vehicle battery designers. (Axsen et al. 2008)

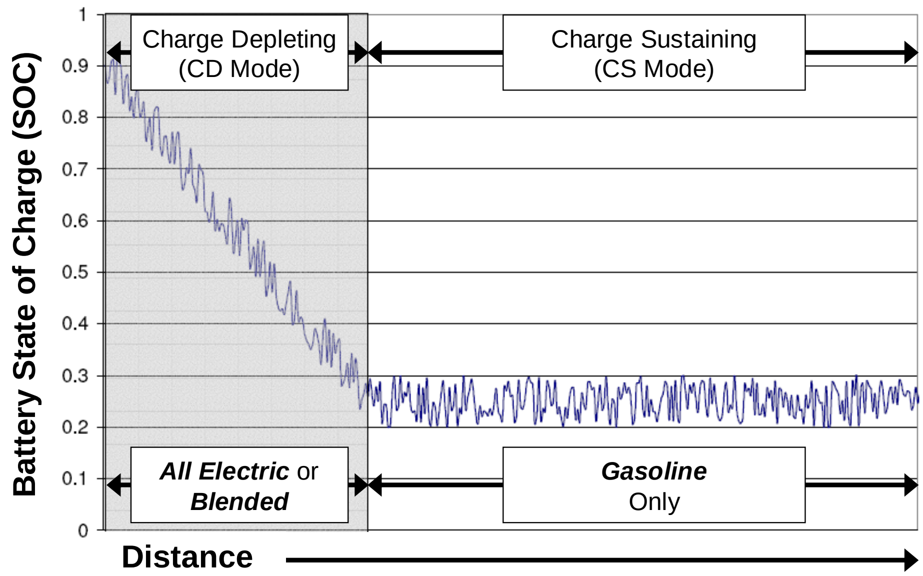


Figure 2–1. Full discharge operation for a PHEV

Credit: Axsen et al. 2008

2.2. Sizing Battery Systems

Perhaps the most important design choice in PHEVs is the sizing of the battery pack because of the high cost of batteries and the impact on potential use of electricity over the life of the vehicle. Generally a large battery will have a significant cost disadvantage, but in most circumstances, driving patterns result in greater percentage use of electricity over the life of the vehicle. Smaller battery vehicles will be more affordable thus may have a wider market. Moreover, large battery PHEVs may be a better fit for the optimal charging goals of utilities. Finding ways to make bigger batteries more affordable will be an important goal for many researchers.

Battery pack energy capacity is typically measured in kilowatt-hours (kWh), power density in kilowatts (kW). A more pertinent way to measure battery capacity for PHEVs—particularly for the buyer— is in terms of "all-electric range" (AER) capability, meaning if the only source of power to the drive train in "charge depleting mode" were the battery, which estimates how long the vehicle can drive on the battery alone. Typically PHEVs are described as having 10 miles of AER, PHEV 10, or 20 miles of AER, PHEV 20 (Duvall 2002).

This is straightforward for series PHEVs but complex for blended PHEVs. In a "series" design PHEV 20, the electricity is depleted in the first 20 miles. In a blended design the AER capacity is combined with the use of liquid or gaseous fuels to produce a "*boosted miles per gallon (MPG)*" range. For example, in one possible blended control strategy a "blended" PHEV 20 will blend its 20 miles of electricity with 20 miles of gasoline to produce 40 miles of "boosted" fuel economy in the "charge depleting mode" (Gondor and Markel, 2007).

This difference between blended and all-electric range AER is important in the market as well as the impact on fuel use and emissions. A series PHEV 20 driven 20 miles each and every day and charged each night would hypothetically never use any liquid or gaseous fuels. Depending on its control strategy a blended PHEV 20 might use gasoline for 50% of its miles. However, if both are driven 40 miles each day and each is charged only once that day, a series PHEV 20 and blended PHEV 20 will use the same amount of gas and electricity. Therefore, a series vehicle seller will boast of its AER "gasoline free 20 miles" while a blended PHEV 20 seller will boast of high gasoline fuel economy for its first 40 miles. Realistically the distribution of miles driven varies greatly from day to day, from week to week, and from household to household. Therefore there is room in the market for both types of designs.

Currently, the cost of batteries is the most important consideration in sizing the battery. Most manufacturers are considering AER in the 10-40 miles size range. Lithium batteries are considered by most to be (Axsen et al., 2008) the only current battery technology capable of powering PHEVs for an acceptable lifetime of 8-10 years. Current estimates of battery costs are in the low thousands for PHEV 10s ranging up high tens of thousands for PHEV 40s. While this report finds that there is much optimism about meeting performance and endurance goals for PHEV batteries, there is less optimism about meeting the cost goals. Some possibilities may include reducing the cost of batteries, either by reducing the size of the batteries, financing the batteries over the life of the vehicle, pay as you go leasing arrangements, and/or value benefits of PHEVs to the energy companies. (SENTECH 2009)

2.3. PHEV Integration With the Grid, Consumer Lifestyles and Impacts on CO_2 and Air Quality

In contrast to HEVs or BEVs, PHEVs drivers have the choice to refuel with liquid or gaseous fuels or electricity for much of their driving; the frequency of recharging and the amount of electricity used will be shaped by their lifestyle, driving patterns, recharging opportunities, and the AER of their vehicle.

PHEVs introduce a new refueling system for the consumer –the electric grid. While BEVs almost certainly demand medium (Level Two, 220 volt) and high (Level Three, 3-phase 220 and 440 volt) fast charging, PHEV 10s and 20s, given their smaller batteries and dual fuel aspect, will not require high power charging and in most cases may work fine with low-power 110 volt outlets for charging. This makes providing charging infrastructure for PHEVs less of a challenge and indeed opens many possible recharging locations for much lower costs at homes, businesses, campsites, parking garages, and shopping areas. Thus in addition to the familiar use of gasoline (although probably less frequent refueling), the consumers develop a new relationship between their vehicle use and the power company.

The recharging of PHEVs is a new load on the power company. As with any new load this implies new demands on the power system from the point of charging all the way to the generation of power and management of the grid. The PHEV could mean trouble or could improve the functioning of the grid and efficiency of power generation capabilities.

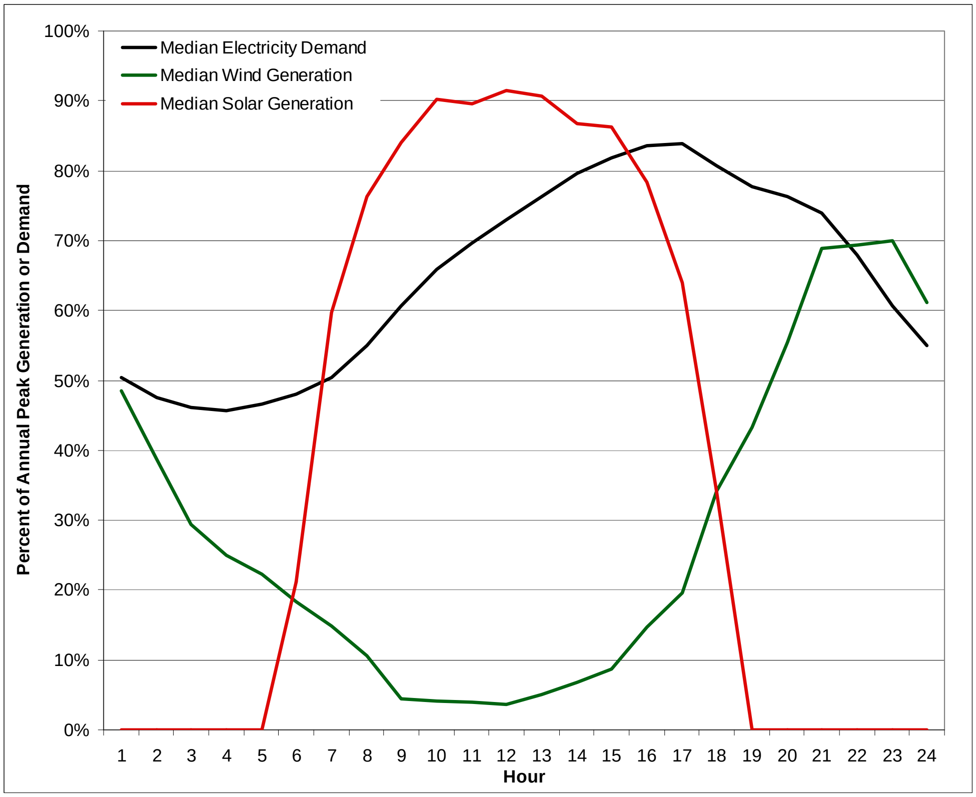


Figure 2–2. Median generation and demand for the month of August

Credit: Christopher Yang, UC Davis

The most frequently imagined scenarios are:

2.3.1. Scenario 1

PHEV and BEV users charge their vehicles at night when most power companies have excess capacity. Promoters of this scenario call this "filling the trough." It has a common sense feeling for the lifestyle of the BEV and PHEV driver:

- Returning from work
- Plugging in the vehicle
- A timer beginning the charge late in the evening when power usage subsides
- The charge finishing early in the morning

The advantage here for the user is not only that the vehicle is charged at night, "off-peak," when the vehicle is parked at home, but the nighttime electricity can be cheaper and on occasion generated using cleaner methods (EPRI 2008). The advantage for the power company is a new source of revenue at night when demand is low and electricity is cheap to provide. This improves the use of power generation investments. From a societal standpoint this is also the best use of the system as it makes the best use of existing infrastructure. Figure 2–2 above shows the average electrical load on the California grid, as well as the complementary sources or wind and solar power. Charging at night would fill in the trough of low electricity load and possibly allow for maximized usage of wind power. The Pacific Northwest National Laboratory (PNNL) has studied the national grid capacity for charging plug-in hybrid vehicles, and concluded that there is sufficient existing capacity to charge up to 84% of U.S. vehicles during nighttime hours (Kintner-Meyer et al. 2007).

2.3.2. Scenario 2

In scenario two PHEVs add load during the periods of highest use, "peak" times of day, thus straining the grid. This is the worst case scenario. An example of such strain is users charging during the afternoons in hot climates when household and commercial air conditioning is heavily used. If even a small number of PHEV or BEV owners were to charge at peak times, the increased load would be unwelcome. While the cost of electricity is potentially the highest at peak or even mid-peak times, it may still be less than the cost of gasoline so motivation may exist to charge at peak times that add to already high electrical loads.

The provisioning of electricity to PHEV owners opens a number of risks and opportunities for power companies to improve their business case, or in the worst case, create an unwanted demand on the grid. Fortunately, in both cases the deployment and development of the PHEV market will happen slowly over decades rather than years (Duvall, Spring 2008). Thus the provision of power and charging systems and the management of this new load will have much time to evolve. In particular, the utility system is moving toward what it is calling the smart grid, a system in which load is managed through new information systems. The PHEV holds some potential to be a positive aspect of that new smart grid as a flexible load that can be controlled (Duvall 2009).

The primary goals of transitioning to electric fuels are the lessening of demand for imported and dwindling fossil fuels, as well as the lessening of CO_2 of the transport sector. What is both interesting and challenging about PHEVs is that the reaching of the goals above is not entirely determined by the vehicle technology alone. Each driver of a PHEV will use a different percentage or ratio of liquid fuels to electricity (also called the load factor, depending on his or her purchase, lifestyle, and travel choices). The sizing of batteries (based on all-electric range), the convenient provision of charging opportunities, the favorable pricing of electricity, and the effective financing of batteries will all contribute to an increased shift of transport energy to electricity, thus achieving the primary goals.

In Figure 2–3, the graph shows that 90% of the hours in a year ratepayers are using only 75% of their capacity. This shows that if existing generation is used wisely, it would be possible to increase the utility factor of current generation capacity without building new generation capacity. This situation would allow the utility sector to evolve over time and grow with the plug-in hybrid market, without needing immediate, expensive capital investments up front.

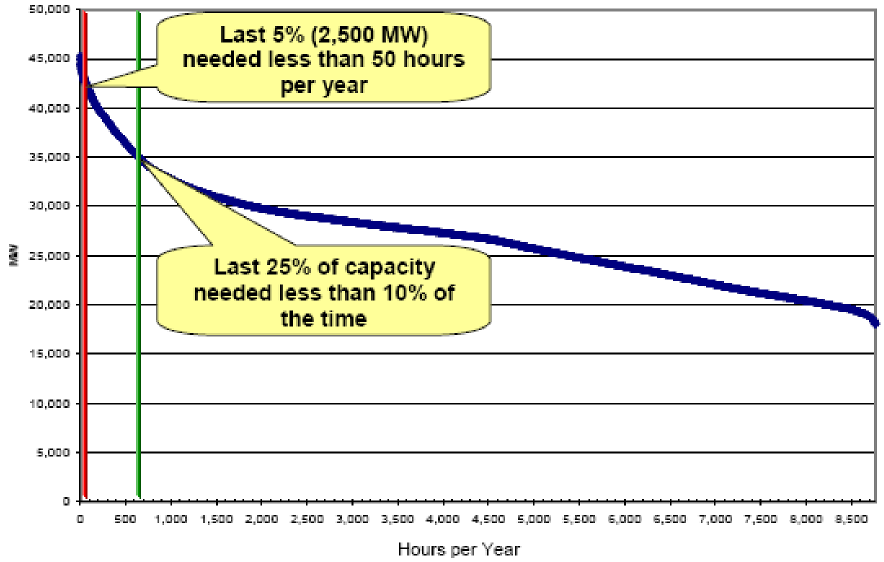


Figure 2–3. California generation utilization

Credit: California Independent System Operator from EPRI presentation at SAE HV Symposium, 2008

3.0 The PHEV Research Center and Roadmap Development

3.1. The PHEV Research Center

The PHEV Research Center was created by the Energy Commission to assist and direct RD&D of PHEVs. The PHEV Research Center was founded at the University of California at Davis (UCD) to take advantage of the long expertise in alternative fuel technologies, as well as market, policy, and lifecycle analysis at the Institute of Transportation Studies, UC Davis' Mechanical, Electrical and Computer engineering expertise with PHEVs, as well as related expertise in Atmospheric Sciences and Civil and Environmental Engineering. The PHEV Research Center is located within UCD's Institute of Transportation Studies.

The center includes the following personnel and participants:

- PHEV Research Center Director and Program Manager
- Plug-In Hybrid Electric Vehicle Research Center Advisory Council (PHRAC), comprised of:
    - California Energy Commission
    - U.S. Department of Energy
    - South Coast Air Quality Management District
    - Electric Power Research Institute
    - Pacific Gas and Electric
    - Sacramento Municipal Utilities District
    - San Diego Gas and Electric
    - Southern California Edison
    - Daimler AG
    - Ford Motor Company
    - General Motors
    - Nissan Motors
- Stakeholders: identified as companies, regulatory agencies, or individuals participating in the development of PHEVs. This includes all of the organizations represented on the PHRAC, as well as other major auto manufacturers and the California Air Resources Board.
- UC Davis researchers.

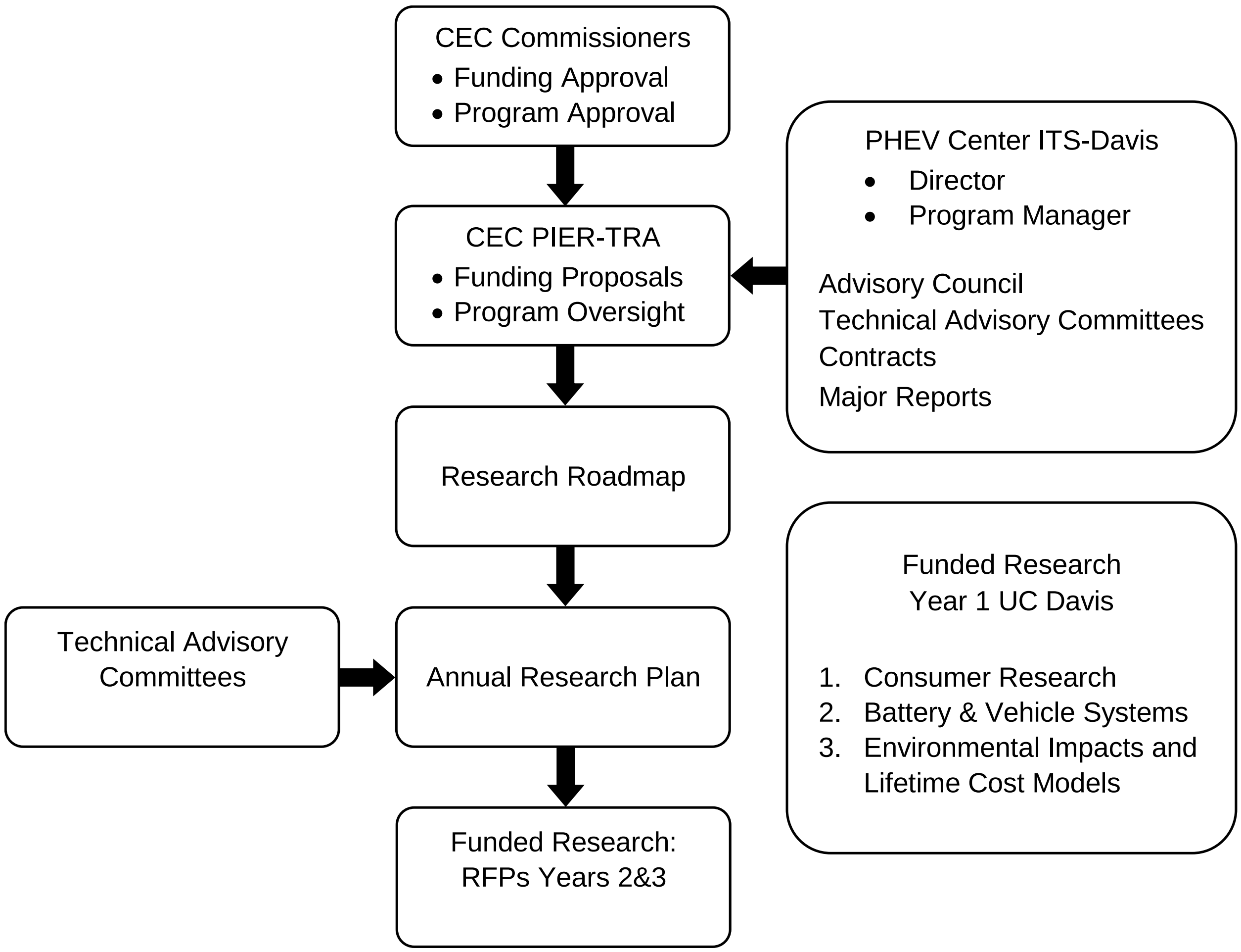


Figure 3–1. PHEV Research Center organizational diagram

3.2. PHEV Research Roadmap Development Process

The PHEV Research Roadmap will inform research decisions related to PHEVs for the State of California. The roadmap will guide choices for each Annual Research Plan for the PHEV Research Center. The roadmap is developed from reviewing the state of research at a broad set of California, national, and international institutions and businesses researching PHEVs, looking for important gaps and opportunities in current PHEV research, obtaining stakeholder input and PHEV Research Advisory Council review.

PHEV research is now being proposed and conducted in a variety of institutions, including businesses such as automobile manufacturers and their suppliers, (notably battery manufacturers), the Department of Energy National Laboratories including Oakridge (ORNL), Argonne (ANL), the National Renewable Energy Labs (NREL) in Colorado, the Pacific Northwest National Labs, and Idaho National Labs. Research is also conducted by major utilities and utility research institutes, such as Southern California Edison and the Electric Power Research Institute. Additionally, there are government PHEV research programs in other parts of the world such as Japan, Sweden, and France. Finally, there are academic PHEV research activities at Universities such as UC Davis, UC Berkeley, UC Irvine, and the University of Michigan.

3.2.1. Workshops, Consultations, and Site Visits

USDOE PHEV Research and Development

The PHEV Research Center director and program manager attended workshops held by USDOE to formulate its research and development (R&D) plan for the USDOE on PHEVs: May 2006; February 2007; and June 2007. These workshops were well-attended by representatives of the major electric utilities and automotive OEMs. These three meetings resulted in a draft USDOE R&D Plan. So far, there has not been a final R&D plan; the draft plan is analyzed and discussed in Appendix B. To date, the USDOE has issued funds for the following activities based on their draft plan:

- Several PHEV battery research programs in its Advanced Battery Consortium (USABC) program.
- A "market study for PHEVs" by Idaho National Labs and University of Michigan. The PHEV Research Center director has discussed this study with University of Michigan faculty.
- A "PHEV Value Proposition Study" by Oakridge National Labs. The director of the PHEV Center is on the guidance committee for this study, and participated in a two-day workshop (Dec. 2007) flushing out the research issues. The guidance committee includes all the major car-makers and utilities.
- USDOE released a request for proposal (RFP) this past December for an OEM lead demo of PHEVs in five cities in the United States (due date for proposals April 30, 2008).
- The director has met twice in Washington with USDOE researchers (Ed Wall, Lee Slezac, and Tien Duong) to discuss potential collaboration with the PHEV Research Center.

USDOE National Labs

The USDOE draft R&D plan is distributing research tasks to the various National Labs. The PHEV Research Center Director has:

- Met with Larry Johnson, Don Hildebrand, and Daniel Santini of Argonne National Labs, gave a presentation on the center, and toured their battery and drive train research facilities in January 2007.
- Met with NREL researchers in February 2007 in Washington, D.C.
- Met with Idaho National Lab (INL) Researchers to discuss PHEV testing work conducted there and in Arizona.
- Dr. Burke, a UC Davis Faculty Researcher, met with Argonne researchers in January 2008.

3.2.2. *Stakeholder Meetings and Facilities Tours*

The director has met with, given presentations on the PHEV Research Center, and discussed PHEV research objectives with representatives from the following corporations at the PHEV Research Center at UC Davis.

- British Petroleum
- Chevron
- Samsung (battery group)
- Daimler-Mercedes (Palo Alto facility)
- BMW (Jan Triblowski)
- A123 Batteries (Dave Vieaux)
- Nissan (many executives)
- Volkswagon (Dr. Wolfgang Schweiger)
- Pacific Gas and Electric (PG&E) (Jill Egbert, Efrain Ornelas)
- Air Resources Board (Annalisa Bevan, Craig Childers)
- Toyota North America (several employees)
- Silicon Valley Leadership Group (Sass Somekh)
- Google (Adam Smith, Alec Proudfoot)
- The Energy Foundation

Tours of research facilities and site meetings

- Electric Power Research Institute (EPRI) (Mark Duvall and Bob Graham) December 2006
- Southern California Edison (SCE) Electric Vehicle Technical Center (Naum Pinsky, Ed Kjaer, Dean Taylor) spring 2007
- Sacramento Municipal Utility District (SMUD) (Bill Boyce) spring 2007
- South Coast Air Quality Management District (SCAQMD) (Lisa Mirasola, Matt Miyasato) spring 2007

The comments of all of the stakeholders that the PHEV Research Center met with were taken into account in developing and prioritizing the research in the Research Roadmap.

3.2.3. *PHEV Research Programs Literature Review, PHEV Conferences, and PHEV Landscape*

In addition to the workshops, meeting and presentations above, the PHEV Center has reviewed recent research plans, research papers, and conference proceedings. The center has also conducted an Internet study of what the authors call the PHEV landscape, which includes advocacy groups and other organizations working in the PHEV world. All of this review material can be found in Appendix D.

3.2.4. *Plug-In Hybrid Research Advisory Council Feedback on Roadmap*

The PHEV Research Center has held three meetings of the PHEV Research Center Advisory Council to gain feedback from the automotive OEMs and other research organizations conducting PHEV-related research on the most important research topics for the Research Roadmap. The first PHRAC meeting included a presentation and discussion of main research topics derived from center meetings and literature review. Results of the first PHRAC meeting and a draft Research Roadmap were presented at the second PHRAC meeting in August 2007 and again in February 2008.

3.2.5. Stakeholder Meeting

The stakeholder meeting was a by-invitation discussion and meeting to review and revise the draft roadmap. The stakeholder meeting was held on the UC Davis campus on April 29, 2008, and included an introduction to the roadmap process and goals by the Energy Commission. Research goals were also presented by the Air Resources Board and were followed by breakout sessions of technical groups to discuss each research area of the roadmap. The stakeholder meeting was attended by 45 representatives from the following stakeholders groups: EPRI, Los Angeles Department of Water and Power (LADWP), ARB, PG&E, UC Berkeley, Mercedes-Benz, Booz Allen Hamilton, Ford, Nissan, CalCars, California Energy Commission, American Automobile Association (AAA), CalETC, San Diego Gas & Electric Company (SDG&E), SMUD, Friends of the Earth, Google, Public Policy Advocates LLC., USDOE, SCE, Volkswagen (VW), CALSTART, Natural Resources Defense Council (NRDC), and California Senator’s staff. The meeting concluded with breakout sessions to discuss the primary topic areas of the roadmap. The results of the breakouts have been integrated into the following roadmap document and are included in the Appendices.

3.2.6. Public Workshop

The public workshop is the final workshop and last stage of gathering input for the Research Roadmap. The public workshop was announced by and held at the California Energy Commission. Input from the public gathered during the public workshop was considered before the final revision and publication of the *California State PHEV Research Roadmap.*

3.2.7. Final Approval

Once the Energy Commission has approved the roadmap, the PHEV Research Center director will submit a list of committee member nominations for the Technical Advisory Committees (TACs) that will review the project plans for future research projects. The PHEV Research Center, with input from the TAC and the Energy Commission, will formulate the final project plan, develop the solicitations, and evaluate applications. The TACs will screen the proposals to research solicitations received by the PHEV Research Center and decide on the most qualified and appropriate research projects that the PHEV Research Center should fund.

4.0 The PHEV Research Roadmap

The Research Roadmap describes the research needed to assist the successful deployment of PHEVs. The roadmap contains a set of "Primary Research Areas," which were identified in the initial development of the center and vetted by the director and staff with the PHRAC and other stakeholders. The first five suggested areas are batteries, vehicle architectures, infrastructure, consumers, and life cycle emissions-cost analysis. The California Air Resources Board (ARB) suggested adding certification and standards, which were generalized to be codes and standards to include issues such as electrical codes and plug and communications standards, as well as emissions certification. These categories have continued to provide useful primary research areas around which the roadmap is organized. The Research Roadmap will guide the development of Annual Research Plans for the center, and based on each Annual Research Plan, solicitations for future research will be developed. Each Annual Research Plan will be approved by the Energy Commission; the resulting solicitations will be distributed. Finally, the Technical Advisory Committees will evaluate the proposals before research funds are distributed.

The director and program manager have been able to participate in a wide variety of sessions, workshops, conferences, and advisory boards in order to gain insight into the current research underway and the remaining research questions related to PHEVs. Beyond bringing PHEVs to the mass market, there are additional research questions related to ensuring their long-term success, potential for added-value benefits for the consumer, and eventual impacts on the utilities if they are successful in large numbers. The groups that the PHEV Research Center has been able to work with and gain insight into potential PHEV research areas include: the U.S. Department of Energy and many of the associated National Laboratories and Researchers, Institute of Electrical and Electronics Engineers, California utility companies, the Electric Power Research Institute, the California Air Resources Board, the South Coast Air Quality Management District, and many automakers.

4.1. The Policy and Research Timeline: Near-, Medium-, and Long-Term Goals, Priorities, and Research Initiatives

In each of the six primary research areas, and for PHEVs overall, the roadmap will include a research timeline that is sensitive to automotive commercialization processes for PHEVs and state policy goals and deadlines.

4.1.1. Existing California Policy Timetable for PHEVs

As a starting point, there are a variety of policy timelines that have been put forth in the laws and statues described in the previous sections.

1. The *State Alternative Fuels Plan* proposes milestone years 2012, 2017, and 2022 (pg 4); to achieve alternative fuel use goals of 9 % in 2012, 11 % in 2017 and 26% in 2022.
2. The SAFP (pg 16) also identifies example alternative fuel mixes, including electricity as a fuel, for the near-term (2007-2015); the midterm (2016-2030) and the long-term (2031-2050).

3. The SAFP (pg 25) identifies Electric Transportation Technologies – Immediate Actions, including Number 4, "Manage EV charging to maximize off-peak power use and support development for up to 290,000 PHEVs and battery EVs in 2012; 1 million in 2017, and 2 million in 2022.
4. The SAFP cites in Table 4 (pg 41) Maximum feasible Alternative Fuel Use Results of 86 million gallons gasoline equivalent (GGE) of electricity use in 2012; 187 million GGE in 2017; and 376 million GGE in 2022.
5. The SAFP describes a potential path to the California 2050 Vision of 4% electricity/hydrogen in 2012; 12% electricity in 2030; and 40% electricity in 2050 (aggressive growth scenario).
6. The ZEV advisory panel lays out a "market" scenario for deployment of ZEVs (and PHEVs), which lays out a scenario of deployment in four stages: first, demonstrations of 100s of vehicles; next a precommercial stage with thousands of vehicles; the following with a commercial phase of tens of thousands of vehicles, and finally a mass commercial phase of hundreds of thousands of vehicles. (2009 ZEV Review, ftp://ftp.arb.ca.gov/carbis/board/books/2009/120909/09-10-4%20pres.pdf)
7. The ZEV Program has considered the role of EVs and potentially PHEVs. They recognize a greater potential of PHEVs to met emissions goals and a greater variety of PHEV designs (blended and parallel; 10-40 miles of AER). ZEV recommendations for PHEVs are now calling for 58,000 PHEVs per year in the 2012-2014 time frame.
8. Additionally, in its draft R&D plan the Department of Energy lays out a three phase development process for PHEVs, a near-term (0-3 years) of "adapted" (converted PHEVs) with 10-20 miles of AER; a second mid-term (3-5 years) development period of Specialized PHEV designs with 30 plus miles of AER; followed by a long term (5-10 years) of "component development for PHEVs with 40 miles of AER".

4.1.2. *Automotive Industry Timetable*

Based on statements from the OEMs Ford and Toyota have begun "adapted" PHEV demonstrations, with hundreds of vehicles planned for 2009. GM has stated intentions to have a "commercialized" (10,000s) extended range electric vehicles (EREVs) (a battery-dominant series PHEV) in the market by 2011/12 if batteries develop as hoped.

4.1.3. Utility Industry Timetable

California utilities and EPRI have been working on PHEVs for the past decade, testing batteries and vehicle designs. SCE and Ford have a collaboration to discover and work on the vehicle interface. In most ways, the utilities are ready for PHEVs, as long as vehicles charge predominantly off-peak.

However, the utilities have been talking often about a more integrated role for PHEVs as a load-balancing technology, given their storage capabilities. That means users can change batteries at optimal times, primarily at night, and perhaps in a more responsive way, receive price signals for more fine tuned time of charging. This may involve the use of "smart meters," which utilities are in the process of installing throughout California. This process should be completed way before the numbers of PHEVs in the market become an issue.

4.1.4. Federal Policy Timetable

President Obama said that he wants one million plug-in hybrids on the road by 2015 and has announced a plan for increasing fuel economy for cars and trucks nationwide to an average of 35.5 miles per gallon by 2016 (Thomas and Elliot 2009). The previous 2007 Energy law required that the average fuel economy increase to 35.5 by 2020. The current average fuel economy is only 25 miles per gallon.

4.1.5. California Research Roadmap Timetable

The PHEV Research Center has defined its vision of the near-, mid-, and long-term periods of PHEV development, based on the production announcements from OEMs and goals for adoption set forth by the state of California, as follows:

Near-term: 2012

The PHEV Research Center expects market introductions to be led by conversions (adapted HEVs) during the next few years in the hundreds (demonstration phase) perhaps evolving into the pre-commercial phase, with thousands of vehicles, hopefully with AER ranges of 10-20 miles.

Mid-term: 2017

The PHEV Research Center expects OEM developed PHEVs with 20-30 miles of AER in the commercial phase, with 10,000s of vehicles in sold the national market each year, and accumulations of hundreds of thousands of vehicles, and component manufacturing for these vehicles.

Long-term: 2022

The PHEV Research Center expects a mass commercial phase, with hundreds of thousands of vehicle sold in the annual market, ranges of 40 miles, and eventual accumulations of millions of vehicles in the national fleet.

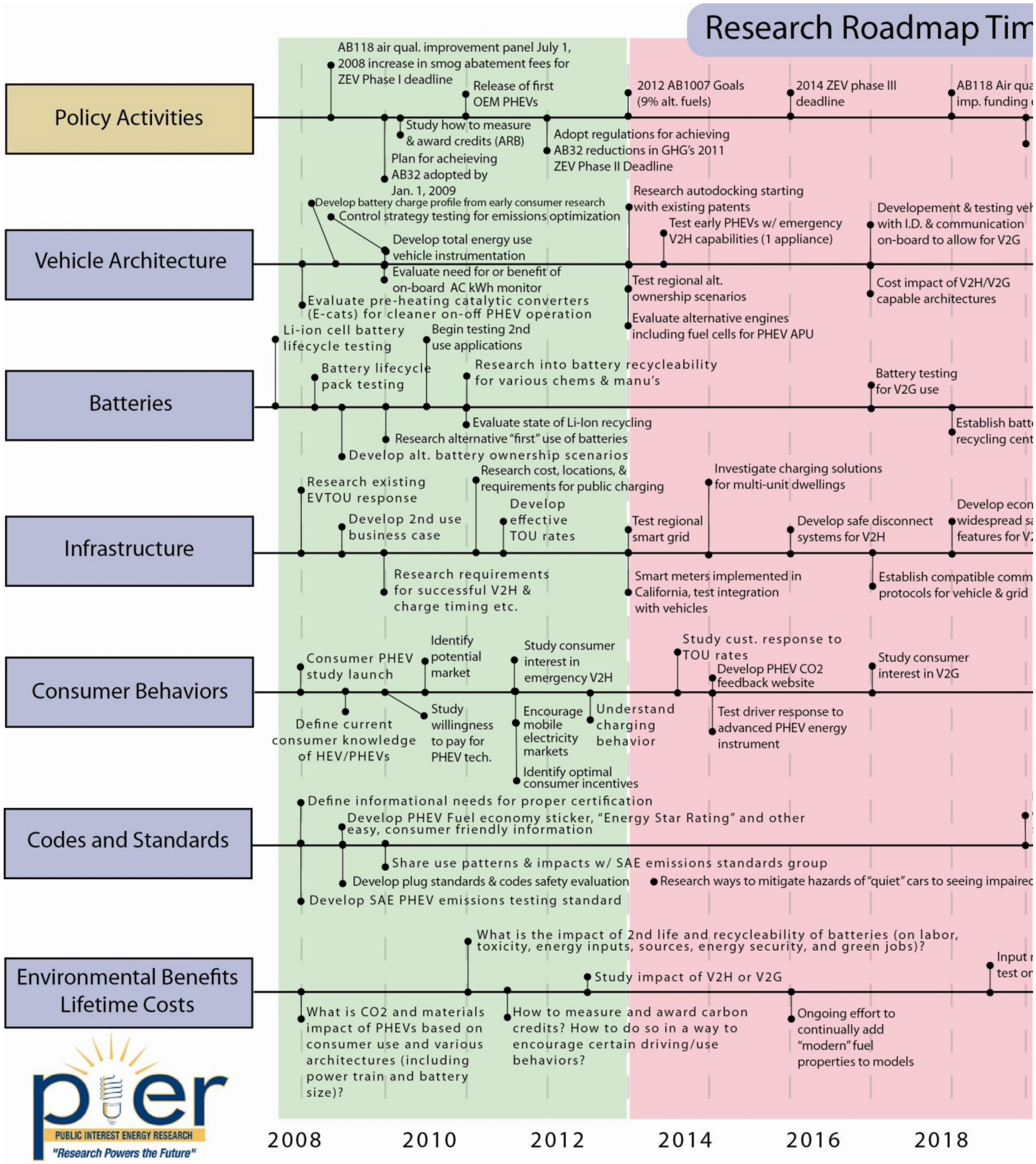
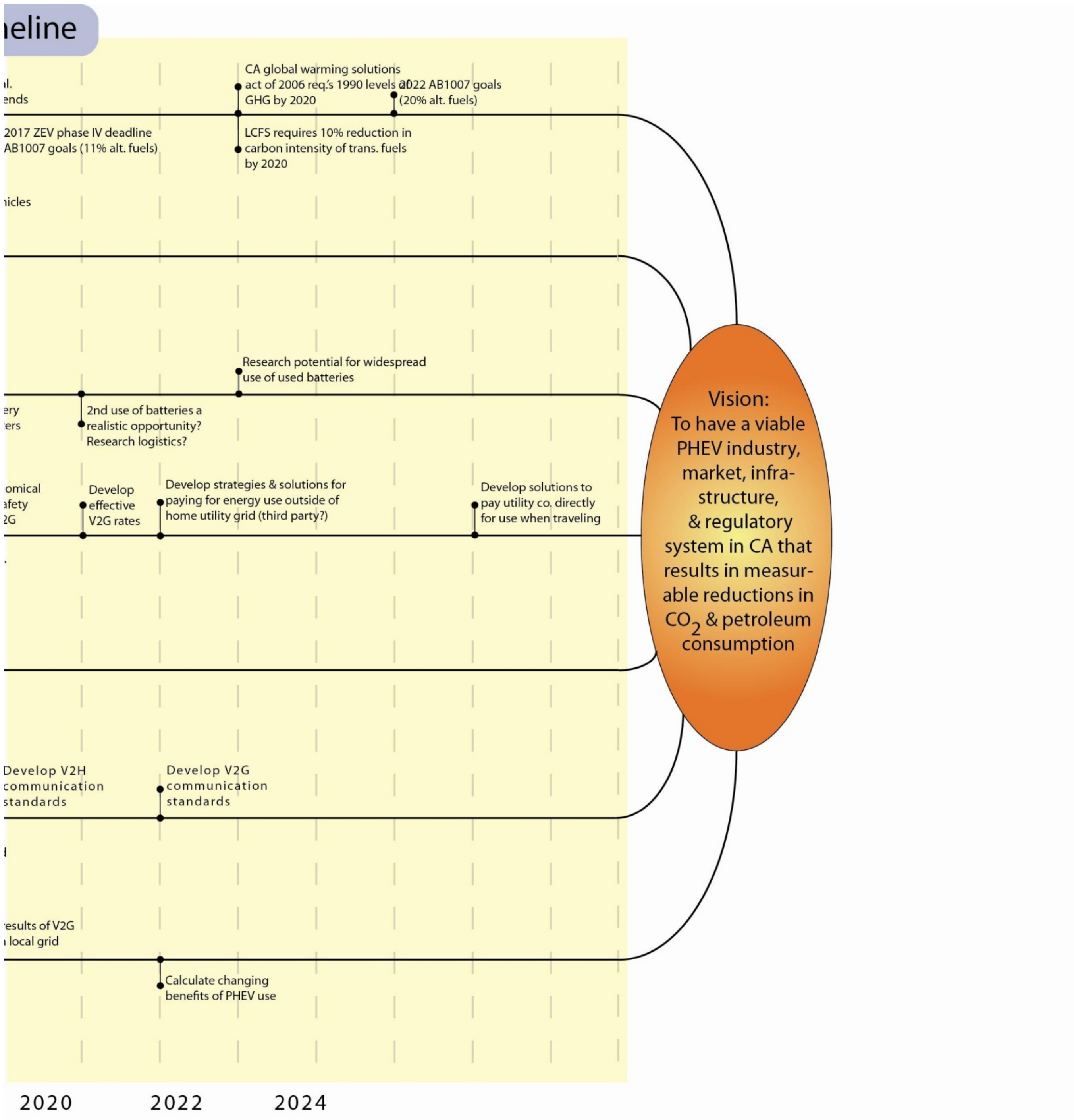


Figure 4–1. Vision of estimated timeline of PHEV development



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ends
CA global warming solutions act of 2006 req.'s 1990 levels of GHG by 2020
2022 AB1007 goals (20% alt. fuels)
2017 ZEV phase IV deadline
AB1007 goals (11% alt. fuels)
LCFS requires 10% reduction in carbon intensity of trans. fuels by 2020
hicles
Research potential for widespread use of used batteries
ery
ers
2nd use of batteries a realistic opportunity? Research logistics?
nomical
afety
2G
Develop effective V2G rates
Develop strategies & solutions for paying for energy use outside of home utility grid (third party?)
Develop solutions to pay utility co. directly for use when traveling
Vision: To have a viable PHEV industry, market, infra-structure, & regulatory system in CA that results in measurable reductions in CO2 & petroleum consumption
Develop V2H communication standards
Develop V2G communication standards
esults of V2G
local grid
Calculate changing benefits of PHEV use
2020
2022
2024

4.2. Six Primary Research Areas

Based upon stakeholder input thus far, the primary areas of public interest research for plug-in hybrids identified in this roadmap are:

- PHEV vehicle architecture and control systems.
- PHEV batteries.
- PHEV infrastructure impacts.
- PHEV consumer behavior.
- PHEV codes and standards.
- PHEV environmental benefits and lifetime costs.

These primary research areas were presented to the PHEV Research Center Advisory Council at both the first and second PHRAC meetings, and stakeholders have confirmed that these are appropriate areas of research focus for the State of California.

Some additional areas of research have been suggested but not yet received full support.

- An additional focus on medium and heavy-duty PHEVs was suggested at the stakeholder meeting and received mixed support. It was suggested that heavy-duty has great per-vehicle impacts and given the battery needs could provide a stronger early market.
- Some members of the advisory board and stakeholders have asked for expanding the scope to include battery electric vehicles and other electric transportation.
- Finally, it was suggested that there be a track focused exclusively on "costs," and investigate ways to lower costs, such as "pay as you go" type insurance impacts on customers, second life applications for batteries, or other strategies for reducing consumer upfront costs.

These suggestions were taken into account; however, the PHEV Research Center has decided to continue with the six primary research areas and incorporate the additional research concerns into the existing research areas.

4.3. Vehicle Architectures and Control Systems

4.3.1. Current Range of RD&D Activities

The following sections describe vehicle architectures and control systems research being conducted by other institutions.

Department of Energy

USDOE has set a goal of designing and modeling PHEVs with 40 miles of range but achieved in three steps. USDOE is focusing effort on "blended" control strategies because of the near-term lower cost aspects. So far it is unclear which research projects are giving full attention to all electric range control strategies. The question is when and how to examine the broad range of PHEV architectures. There is still quite a bit of debate as to how to best use the electricity on-board the vehicles, and this will likely be resolved through a blend of private and public research to optimize the vehicle architecture, public policy driving specific AER requirements, and consumer preferences for high average fuel economy or all-electric-range operation. The USDOE blended-mode operation would likely start out to be the most cost-effective solution and would gradually lead to longer AER as battery costs go down and consumer preferences are better understood.

Original Equipment Manufacturers

There are several OEMs that have recently announced their plans for PHEVs in the next two to three years. GM has proposed the "Volt," described as an EREV, to have 40 miles of all electric range, using a series hybrid power train and lithium-ion (nano chemistry) batteries.

Toyota has announced plans for a PHEV Prius also using lithium-ion (cobalt) batteries and its signature power split power train. It is likely that the Toyota PHEV will operate using a blended-mode strategy. Both Toyota and GM are aiming for vehicles to be available in the 2010-2011 time frame.

DaimlerChrysler built approximately a dozen Sprinter PHEVs that are being tested and demonstrated in various situations and environments in the United States, using both NiMH and Li-ion technology batteries and a pretransmission parallel power train design. Production of the Sprinter PHEV is unknown is the wake of the split between Daimler and Chrysler. Chrysler, at the 2009 Detroit Auto Show, unveiled new electric and plug-in hybrid concept vehicles and discussed research goals of their Environmental New Vehicles (ENVI) group (Neil 2009). The ENVI group was disbanded in November 2009 after the company was acquired by Fiat, although it continues to have ongoing research on electric drive vehicles (Krolicki, 2009).

Ford is also developing prototype PHEV Escapes and working with SCE to test these vehicles and their interactions with the utility grid. They have not yet announced production plans or dates for the PHEV Escape. Ford has shown a design that includes a flex-fueled engine. Other vehicle manufacturers are now discussing their plans for PHEVs in the near future, although the specific power train and battery choices are still unknown.

A number of other manufacturers have recently announced designs. Volvo has designed a PHEV concept vehicle, designed at its California facility, which has a diesel engine version, shown at the 2008 Frankfurt car show. It has not announced plans for production. VW has also announced a design that uniquely employs three clutches in its drive train. A Chinese battery company has formed an automobile company, called BYD, and has shown a PHEV design at the 2008 Geneva and Detroit auto shows.

EPRI

EPRI has focused on AER strategies in its vehicle modeling efforts. Recently, Mark Alexander of EPRI presented their modeling research comparing conventional, pre-transmission parallel, power split, and series power trains in the same vehicle, looking at the torque delivery characteristics of each power train at the Electric Vehicle Symposium 23 in December 2007.

Universities

Until recently, most vehicle research at the university level was focused on hybrid vehicles but not plug-in hybrids. An exception to this is UC Davis, with Dr. Andrew Frank leading the design and development of PHEVs for student competitions funded by the U.S. Department of Energy. His vehicles have evolved over the past three decades from flywheels, through pre-transmission parallel sedans with NiMH batteries using gasoline, to four-wheel-drive sport-utility vehicles with Li-ion battery packs and ethanol as the liquid fuel. The UC Davis PHEVs have consistently been battery-dominant pretransmission parallel hybrid designs with large battery packs, extensive all-electric driving range and small engines.

Additional PHEV prototypes have been built by San Diego State University, led by Dr. James Burns, who has built three prototypes over the past 10 years. His research concentrates on diesel fueled series hybrid vehicles with high performance characteristics.

Table 4–1 shows research institutions working on vehicle architecture related research. All automakers are working on some PHEV related vehicle architecture and control strategy research, although not all are open in discussing the type and extent of work that they are doing related to plug-in hybrids. Some companies are focusing larger efforts into plug-in hybrids than others and are more open in sharing their research and production goals, such as GM, Ford, Toyota, and in 2009 Chrysler, also began openly discussing their work (Neil, 2009).

Vehicle Architecture and Control Strategies	Powertrain Modeling	Vehicle Aerodynamics	Weight Reduction	Control Strategy Testing
DOE/National Labs	ANL			NREL/ANL
OEMs	All	All	All	All
Universities	UC Davis			UC Davis
EPRI	EPRI			EPRI
Utilities				
ARB				
AQMDs				
Other				

Table 4–1. Ongoing research in vehicle architecture and control strategies areas

4.3.2. *Gaps Analysis*

While there is significant research ongoing into the various areas of vehicle architecture, there is still room for additional research, especially basic non-proprietary research, of drawbacks and benefits of various architectures and control strategies. In particular, innovative control strategies may solve some of the drawbacks of engine-off hybrids, such as cold-start emissions.

4.3.3. Stakeholder Meeting

The stakeholder meeting noted that there are a wide range of OEM designs, and this would continue as a way for automakers to differentiate themselves and to meet varying consumer requirements. It would not make sense to put research efforts into designing drive trains; however, it does make sense to continue to model PHEV drive trains and control strategies in order to estimate energy needs and emissions impacts of various design pathways.

4.3.4. PHRAC Feedback

The PHRAC suggested that further research into the vehicle architecture area be conducted to answer specific, necessary unknowns, such as cold-start emissions control strategies. Since there has been, and continues to be, such extensive work on vehicle architecture development, including vehicle modeling, the PHRAC agreed that it was important to facilitate communication with the vehicle OEMs and other research groups working in this research area.

4.3.5. Key PIER Opportunities

Vehicle architectures and control strategies are primarily funded within the OEMs. Already Toyota, GM, and Daimler have developed proprietary architectures. However there are areas of interest for the state of California. In particular, each architecture will have specific emissions implications and will need to be characterized for the energy and greenhouse gas-planning going on in the state. In addition to testing the vehicle power train architectures within computer simulation programs, there are an almost limitless number of possible control strategies that can be implemented in the various power train architectures. In particular, the engine on/off operation inherent in all HEVs can make achieving required emissions levels challenging and poses a prime example of necessary research. Research facilities can test some of these unique and innovative control strategies fairly reliably and economically within these computer simulation programs.

In the next stages of research, there will be opportunities to develop and test connection and communication standards and protocols for connecting the vehicle to the grid. The possibilities of "smart cars" connected to an intelligent grid system and the potential for V2G allow for an almost unlimited amount of research into the easiest and most efficient ways for these two systems to interact and communicate.

The research needs and opportunities for vehicle architecture research are shown in Figure 4–2: Vehicle Architecture Research Timeline and corresponding Table 4–2. Vehicle architecture public interest research task list.

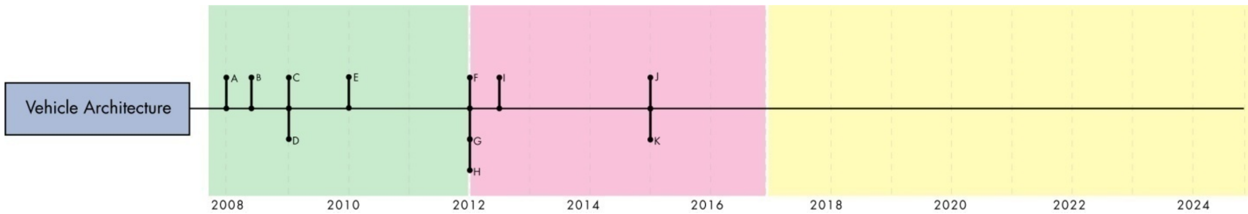

Figure 4–2. Vehicle architecture public interest research timeline

Item	Year	Research Task
A	2008	Evaluate pre-heating catalytic converters (E-cats) for cleaner on-off PHEV operation
B	2008	Develop battery charge-discharge profile from early consumer research
C	2009	Control Strategy testing for emissions optimization
D	2009	Develop total-energy-use vehicle instrumentation
E	2010	Evaluate need for or benefit of on-board AC kWh monitor
F	2012	Research autodocking starting with existing patents
G	2012	Test regional alternative ownership scenarios
H	2012	Evaluate alternative engines, including fuel cells, for PHEV APUs
I	2013	Test early PHEVs with energency V2H capabilities (~1 appliance)
J	2015	Development and testing of vehicles with I.D. and communication on-board to allow for V2G
K	2015	Compare cost impacts of V2H/V2G capable architectures

Table 4–2. Vehicle architecture public interest research task list

4.4. Batteries

4.4.1. Current Range of RD&D Activities

The key technology that may lead to the widespread adoption of hybrids is the battery. In particular, the battery cost will be key to the success of the PHEV, but there are also power, energy, and safety requirements for PHEVs. The current hybrids on the market use nickel-metal-hydride batteries; however in the past years, new battery manufacturers have made strides in the lithium-ion battery technology that will likely lead to the Li-ion being the dominant battery for PHEVs.

Current research focuses on comparing and studying the various Li-ion battery chemistries, particularly on their comparative lifetimes and safety. Additional analysis is required to find opportunities or business cases that will bring the cost of these batteries down to an affordable level for mass market adoption. The following sections describe battery research being conducted by other institutions.

Department of Energy

The U.S. Department of Energy is conducting PHEV-related battery research in the following areas (from the USDOE PHEV R&D Plan, Page 16)

> "**Technology development** in partnership with the USABC includes benchmark testing, technology assessment, and full system development currently focused

on developing and evaluating Li-battery cells, packs, and full systems for hybrids.

"**Applied research** addresses cross-cutting barriers that face those Li-ion systems closest to meeting the requirements for vehicle applications. Five national laboratories (Argonne, Berkeley, Brookhaven, Idaho and Sandia) participate, each bringing its own areas of expertise to address life, abuse tolerance, low temperature performance, and cost.

"**Focused fundamental research** addresses chemical instabilities, promoting a better understanding of why systems fail, modeling failure and system optimization, and investigating new materials. The work includes nickelates, phosphates, and new higher energy materials such as composite cathodes and non-graphitic anodes. Three national laboratories (Argonne, Berkeley and Brookhaven) and twelve universities currently participate in this activity."

USDOE is working with the USABC to develop battery development goals for near-, mid-, and long-term applications in PHEVs. They have identified goals for battery cycle life, cost, specific power, and specific energy and are working with various other organizations toward achieving these goals. In particular, Argonne National Labs have been conducting tests of batteries, bench testing, life-cycle testing, and with Idaho National Labs testing batteries in vehicles. DOE has plans to develop a set of PHEV mules in which batteries are tested.

Original Equipment Manufacturers

Most of the automakers that have plans for an upcoming PHEV are working closely with battery manufacturers to conduct the basic battery research and development work to meet their specific battery needs for a specific PHEV design. The work being conducted at the battery manufacturer level is the basic proprietary chemical and packaging research to optimize their batteries for their particular applications. There are known cooperative research efforts between GM and A123 as well as Cobasys (Saturn Vue), and Compact (LG Chem). Toyota is working with, and in fact owns a portion of, Panasonic. The DaimlerChrysler Sprinter PHEV demonstration vehicles are using Saft Li-ion and Varta NiMH batteries. Volkswagen has announced a partnership with Sanyo.

Utilities

Southern California Edison's Electric Vehicle Technical Center has been conducting battery life cycle testing for many types of batteries for many years. Their research includes lifecycle testing of lead-acid, nickel-metal-hydride, and lithium-ion batteries from many different battery manufacturers, and includes testing under a variety of controlled temperature conditions. Most of their testing is on single batteries or sub-packs; however, they do conduct some performance baseline testing of batteries in-vehicle with cooperation from the manufacturers.

Batteries	Fundamental Chemistry Research	Lifecycle Testing	Battery Business Cases/Cost Reduction	Recycling	Battery Production	Shipping and Handling
DOE/National Labs	ANL	ANL				
OEMs	Saft, Valence, Panasonic, A123				Toyota & Panasonic, Nissan & NEC, etc.	
Universities	MIT, UT, UC Berkeley	UC Davis				
EPRI		EPRI	EPRI	EPRI		
Utilities	Hydro-Quebec	SCE				
ARB						
AQMDs						
Other		USABC	USABC			

Table 4–3. Ongoing research in battery areas

4.4.2. Gaps Analysis

Though there is an abundance of basic chemical and battery formatting research being conducted by OEMs, in this case the battery manufacturers, there is still application-specific research necessary. There are a number of programs testing and benchmarking lithium batteries, however the importance of this issue combined with the complexity of various control strategies possible in PHEVs may warrant multiple programs studying lithium technologies and benchmarking. The ongoing battery research occurring at various research institutions is shown in Table 4.3.

Batteries must be bench-tested under a variety of advanced vehicle control strategies and environments that more closely resemble their real-world use. Certain battery characteristics may be more applicable to very specific control strategies, such as blended electricity and ICE use versus an all-electric range strategy. Much of this research would coincide with the advanced vehicle architecture and control strategy modeling efforts. The primary barrier for batteries remains their high cost. Currently, much of the advanced battery research is focused on high-tech processes and materials, like nano-particles. Given the high cost issue, some attention is warranted to research lower cost approaches such as flat pouch formats.

Currently, there has been minimal research into the second-use of batteries after their primary vehicle application, or in improving efficiency or logistics of recycling advanced batteries on a large scale. There are also opportunities for research in how to define end-of-life for primary or secondary applications, what possible secondary applications may be, and how to integrate the controls of various formats, manufacturers, or even chemistries into a single secondary application.

4.4.3. Stakeholder Meeting

At the stakeholder meeting breakout group that discussed ongoing battery research and research needs, the stakeholders noted that some areas of research are already well under way, such as OEM testing and safety analysis. However, it may become important for the state of California, given security and economy issues, to understand the economic barriers, environmental issues or other relevant aspects of locating automotive lithium battery manufacturing in California. The stakeholders suggested that perhaps the PHEV Research center should evaluate the Enerdel plant in Indianapolis.

It was suggested that potential "control strategies" be modeled to point to various tradeoffs, such as minimizing CO_2 and petroleum use, maximizing AER, or supplying V2H or V2G, or mobile electricity uses (such as power tools). These value-added benefits or modified control strategies could have long-term effects on the lifetime of the batteries in PHEV applications that should be researched.

4.4.4. PHRAC Feedback

The PHRAC suggested that there may be opportunities for the PHEV Research Center to fund future research into the development of potential second-use market applications of used PHEV batteries. They also suggested that in the long-term, the feasibility and logistics of second-use applications would need to be thoroughly researched. In addition, the PHRAC suggested the PHEV Center fund research and development of battery temperature management approaches and effects of temperature management on battery life and performance. They suggested research into the comparative cooling techniques used with batteries, such as water, coolant or air cooling, including the effect not just on cycle life but on calendar life as well.

Some of the questions that came up in the second PHRAC meeting include how to define "end-of-life" for a battery, both for vehicle use and stationary use. Also, the discussion continued on the value, market, and potential use scenarios for PHEV batteries in stationary applications, either to prime the PHEV battery market, or as a second-use application for batteries at the end of their vehicle life.

4.4.5. Key PIER Opportunities

Batteries are widely understood to be a significant limiting factor in the production and cost of PHEVs. Basic battery research at both the chemical and manufacturing format levels are well funded by large battery companies who are well aware of and motivated by the goal of battery-operated vehicles. The U.S. government also funds basic battery research, at high levels and looking well into the future. It has recently increased the funding of PHEV specific batteries to $9 million annually. There are some special areas of research on PHEV batteries that will be useful for the center to pursue.

The continued testing of various protocols for benchmarking the performance of batteries and testing their lifetime performance capabilities, both in terms of vehicle operation and calendar life, will continue to be an important aspect of battery research, especially as new chemistries and technologies evolve.

Equally important is understanding the full monetary and "cradle-to-grave" lifecycle costs of batteries. Battery manufacturers and automakers are not forthcoming about the true cost of batteries due to the competitive nature of the industry; therefore, figuring out the real cost of batteries is a challenge. In addition, the industry must understand the full lifecycle costs, in terms of manufacturing energy, use of resources, and upstream emissions, etc. of the batteries as a component in the PHEV in order to measure and comprehend the beneficial value of plug-in hybrids. Both the component monetary cost and lifecycle cost will affect the final vehicles designed and manufactured and should be incorporated into the lifecycle emissions reductions from PHEVs.

The cost and lifecycle cost of the battery are both a significant component of the total vehicle cost, and investigating ways to extend the lifetime of the battery, and therefore spread out the cost of the battery over a longer period, is a research topic that was brought up on several occasions. The "second use" or "second life" of a battery may reduce financial cost and extend the useable life of the battery in a much less demanding environment than a vehicle. Sandia National Laboratory did a study of the potential second-use applications for nickel metal hydride batteries from BEV and hybrid applications (Cready et al. 2003); however, no thorough study of the potential costs and applications for lithium ion batteries from PHEV applications has been conducted. Lithium ion batteries age at a different rate than both NiMH or lead acid batteries, and the use patterns from a PHEV are very different from use patterns seen in either a BEV or HEV application. This opportunity for second-use research may be one of the most pressing research questions that can reduce the initial vehicle cost by allowing for a residual value in the battery and spreading out the lifecycle costs of battery manufacture.

Finally, the question of recycling the battery at its end-of-life is something that must be addressed before significant quantities of these large format batteries are produced. Currently, the capability for recycling small format batteries exists in the United States; however, there is not yet the capacity (or the need) for recycling large format batteries. Understanding the "cradle-to-grave" lifecycle of the battery must include the materials regained from the battery recycling process. In addition, some system of requiring that the batteries be recycled must be established.

The expense and lifetime expectations of the batteries in a plug-in hybrid electric vehicle are a significant constraint limiting the production and release of PHEVs to the public. In order to encourage the development of PHEVs, research should be directed at developing a realistic business case for the batteries in PHEVs, including both primary and possible secondary use scenarios. In addition, this business case should include the cost and feasibility of recycling the batteries at their end of life.

The research needs and opportunities for battery research are shown in Figure 4–3 and the corresponding Table 4–4.

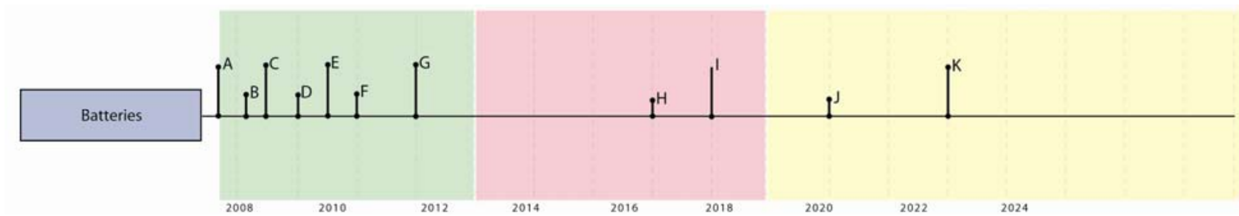

Figure 4–3. Battery public interest research timeline

Item	Year	Research Task
A	pre-2008	Li-ion battery cell lifecycle testing
B	2008	Li-ion battery pack lifecycle testing
C	2008	Develop alternative battery ownership scenarios
D	2009	Research alternative "first" uses of li-ion batteries
E	2009	Begin testing 2nd use applications
F	2010	Evaluate state of li-ion battery recycleing
G	2011	Research into battery recycleability for various chemistries and manufacturers
H	2015	Battery testing for V2G use
I	2016	Establish battery recycling centers
J	2018	Research logistics of 2nd use of batteries as a realistic opportunity
K	2020	Research potential for widespread use of used batteries

Table 4–4. Battery public interest research task list

4.5. Infrastructure Impacts

4.5.1. Current Range of RD&D Activities

PHEVs are a new customer for the utilities, adding load to the grid. Ideally, PHEVs will add load off-peak, when rates are low and capacity is underused and someday possibly adding storage capacity to the system through V2G. PHEVs could potentially offer a new way for utilities to manage loads, through smart grid-to-vehicle (G2V) charging. Finally, if done properly, PHEVs may offer distributed storage to work in concert with fluctuating renewables like wind and solar that are not base loads.

Several recent studies by national labs and EPRI have indicated that there is sufficient capacity in the grid to handle the additional energy needs of PHEVs if charged off-peak. Additionally, as the market for PHEVs develops over at least two decades, the grid will have plenty of time to adapt to the added load from PHEVs.

The degree to which PHEV charging will eventually create peak loads or help balance the load on electricity generation by raising the load during off-peak demand valleys is an important area of research and concern, especially to utility stakeholders. In the short-term, methods for encouraging off-peak vehicle charging and managing the additional charging load should be addressed. Finally, the potential for value-added benefits, such as emergency vehicle-to-home or peak-shaving vehicle-to-grid are discussed as a possible long-term benefit of PHEVs. The following sections describe the types of research into infrastructure impacts that have been conducted or are underway at other institutions.

Department of Energy

The results from a two-day DOE workshop (DOE 2007) concluded that PHEVs could substantially reduce petroleum consumption by shifting to electricity as a fuel, and that off-peak generation was currently capable of handling a large number of vehicles; therefore, that grid power would not be a barrier to the adoption of PHEVs. The DOE is looking into the impacts and potential benefits that PHEVs would have on the grid from several directions.

DOE Draft Roadmap

The DOE Roadmap concluded that the two main interests for research, in the short term, were the specific requirements for the interface between the vehicle and the grid for charging, and the impacts of charging on the grid and utilities. They concluded that other aspects of the vehicle-grid interface, such as vehicle-to-grid, were long-term research issues and would not be a research area at this time. In the roadmap, DOE states that the vehicle-utility interface work would continue at facilities that are currently involved in development, testing, and demonstration, Argonne National Lab and Idaho National Lab (Wall 2007).

The second area of research, that of the impact of PHEVs on the utilities and electrical infrastructure, would be conducted by the DOE Freedom Car and Vehicle Technologies program (FCVT) collaborating with the Office of Electricity to ensure that updated analyses performed by ANL, EPRI, and PNNL are consistent and take into account the latest information on both the vehicles and the grid.

National Labs

Pacific Northwest National Laboratory concluded a study entitled *Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional US Power Grids: Part 1: Technical Analysis* in early 2007 (Kintner-Meyer et al. 2007). This report concluded that the current grid, using existing idle capacity of the electric infrastructure, was capable of meeting the majority of the daily energy needs of the U.S. light-duty vehicle fleet were it to be primarily PHEVs. The second part of the paper "Part II: Economic Assessment" discusses the potential downward pressure on rates as revenues for utilities increase in the absence of new investments for generation, transmission, and distribution. No environmental assessment was conducted at this time.

EPRI

In late 2007 EPRI published the study *Environmental Assessment of Plug-In Hybrid Electric Vehicles*, which included two parts: *Volume I: Nationwide Greenhouse Gas Emissions,* and *Volume II: US Air Quality Analysis*. These studies are thorough in their evaluation of PHEVs on the grid, and include the projected growth and emissions of the grid of the future (Kliesch and Langer, 2006).

Original Equipment Manufacturers

Part of the plan for the Ford/SCE research project involving the PHEV Escapes is to evaluate the grid impacts of the PHEVs, as well as demonstrate some of the potential future value-added benefits of a PHEV, such as emergency backup power, V2H, and V2G. This partnership will include up to 20 PHEV Ford Escapes.

Universities

The University of Delaware is looking into V2G as well as the integration of renewables with the electrical grid and linking those renewables to plug-in vehicles. In addition, UC Davis is also doing infrastructure modeling on linking plug-in vehicles with renewables such as wind and solar power.

Utilities

Several utilities are interested in understanding the impacts of plug-in hybrids, these include Xcel Energy, Duke Energy, Pacific Gas and Electric, Sacramento Municipal Utility District , San Diego Gas & Electric, and Southern California Edison, among others. Many of these companies are beginning to look into their capacity for increased demand due to plug-in hybrids and understanding how they might best manage that load. See the previous section on the discussion of the Southern California Edison/Ford Motor Company research partnership, which will also look into V2H and V2G questions.

Others

In addition to the major PHEV players discussed above, several other entities are working on research related to the interactions between infrastructure and vehicles. These include CALSTART/WestStart and the start-up companies Coulomb and Better Place. Coulomb Technologies is developing a public charging system that would allow users to have a membership and use a membership card to gain access to secure public charging stations. Better Place is developing battery electric vehicles in cooperation with Renault and is planning to install many proprietary public charging stations and some battery pack exchange facilities in places like Israel, Denmark, and Australia.

The entities with ongoing research related to the infrastructure impacts of plug-in hybrid vehicles are illustrated below in Table 4–5.

Infrastructure Impacts	Grid Capacity	Distribution Capacity	Grid-Vehicle Integration/ Communication	Public Charging Infrastructure	V2G (Can we merge with Grid-vehicle integration?)	Wind and Solar Integration
DOE/National Labs	PNNL, ORNL	PNNL			PNNL,NREL	ANL, NREL
OEMs					Ford	
Universities					UC Berkeley, U of Delaware	U of Delaware, UC Davis
EPRI	EPRI	EPRI	EPRI	EPRI	EPRI	EPRI
Utilities	Most	Most	Most	Most	PG&E, SCE, Austin, Xcel, Duke	PG&E, SCE, Austin, Xcel, Duke
ARB					ARB	
AQMDs				SCAQMD	SCAQMD	
Other	NRDC			IBM, Coulomb, ETEC, City of SF	WestStart, Better Place	

Table 4–5. Ongoing research in infrastructure impacts areas

4.5.2. *Gaps Analysis*

While the impacts of PHEVs on the nationwide grid have been recently studied, there are still questions regarding the regional impacts of rapid PHEV adoption, in particular regional distribution capacity and impacts. In addition, the current models take into account the fairly slow charging profile, and low impact, of 110V on-board charging, which is what is expected in early PHEVs. Additional grid impacts modeling will be necessary if the automakers change their approach, for example, adopting fast-charging, and as the traction battery size in PHEVs increase over time. All of the current models are based on estimates of battery size, rate of adoption of PHEVs, charging style, and consumer charging patterns. These grid models also look at the current grid and likely expansion of the grid in analyzing the emissions impacts, but this could change with a change in political or international climates, for example, allowing for the construction of new nuclear generation in the United States.

4.5.3. Stakeholder Meeting

The stakeholder meeting developed the following research topics within the infrastructure impacts research area:

- A near-term study of recharging needs by consumers, especially opportunity charging for those urban segments of the market (apartments for example) that do not have charging abilities currently. This would also include investigating the need for 120V vs. 220V; codes and standards (This overlaps with consumer research in Section 4.6).
- A midterm study to determine the system utilization impacts of "off-peak" recharging (so as to inform rate cases)
- A midterm study to determine the system topology (the overall integration of systems) of G2V, V2H, and V2G.

- Long-term study to quantify value of PHEVs as distributed energy source in disaster situations.
- Long-term study to determine logistics (SAE is also working on this) of implementing smart charging.
- Long-term study to determine impacts of large number of batteries charging in a localized distribution area.

4.5.4. PHRAC Feedback

The PHRAC has suggested, that given the several recent studies of potential capacity in the grid, for the United States as well as California, that additional studies focused on grid capacity may not be high-value research.

4.5.5. Key PIER Opportunities

In the past year, there have emerged a number of studies of utility impacts by EPRI, PNNL, the American Council for an Energy Efficient Economy, etc. Many of these studies have concluded that utilities have sufficient nighttime generation to handle PHEVs. In consideration of the timeline of introduction of PHEVs, it would appear that further studies of this are a low priority. There will be room for improvement in the future to take into account new knowledge on consumer charging behavior, new generation capacity, and actual vehicle specifications when the first PHEVs arrive on the market.

The near-term research relates to how consumers will use the current infrastructure. This includes studying the satisfaction of early PHEV consumers with the current 110V charging infrastructure and evaluating their satisfaction with cost, availability, and speed of charging. This will answer questions about whether the current household infrastructure is sufficient to satisfy initial market growth as battery and vehicle manufacturers roll out vehicles and iterate designs.

In addition, there are opportunities to study the effectiveness of a variety of time-of-use (TOU) based rates on shifting charging to the off-peak times when they have a positive impact on the electricity infrastructure. Eventually there will be opportunities to test and evaluate devices designed to improve the consumer experience of plugging-in, such as the new smart meters, timers to delay charging, and vehicle interfaces to simplify the charging experience.

The computing power on-board these advanced vehicles will likely develop much faster than the utility grid the vehicle is connecting to, and there will be research opportunities in the midterm to maximize the benefits and charging optimization possibilities of on-board computers.

There is also a need to research and understand the methods and benefits of battery recycling. The ability and infrastructure for PHEV battery recycling will be necessary to the success of PHEVs to ensure a smaller carbon footprint and consumer acceptance for the PHEV as an environmental solution. There is existing capacity to recycle small format batteries of many chemistries, including Li-ion, but currently very little knowledge and nearly no capacity for recycling large quantities of large-format Li-ion batteries. According to Daniel Kinsbursky of

Kinsbursky Brothers Inc. Recycling, the Li-ion batteries can be recycled using a cryogenic process to render the batteries inert, and then shredding the inert remains into Li-ion fluff for plastics recycling and valuable metals. Additional research is necessary to optimize this process for efficiency and to investigate additional methods for recycling.

One research opportunity is to continue to study how PHEVs might contribute in the future to renewable energy and load leveling through V2G and/or V2H but also to understand impact of mobile electricity. That is the added impact of using batteries and charge connections to power loads in parked vehicles, (such as the heating, ventilation and air-conditioning system), or use the parked vehicle to power local power needs (such as in a campground). There has been a lot of discussion about the possible value-added benefits of PHEVs in supplying emergency backup power, or even vehicle-to-home or vehicle-to-grid connectivity in the future. These are widely understood to be many years in the future, as there are still many questions that remain about the feasibility of any of these situations.

Initially the technical feasibility, in terms of the technical requirements for both the vehicle and utility systems and potential applications must be understood. This may include linking the battery to the advanced metering infrastructure currently being installed throughout California, as well as the potential second-use battery applications such as stationary solar energy storage. Next, the business case for both the utility and the consumer must be evaluated. For utilities, this would include evaluating whether any additional investment or rate structure is worth the added benefits of distributed energy storage on board the vehicles. For consumers, this would include evaluating if the additional "wear and tear" on the battery, which may reduce the lifetime of the battery in the vehicle, is offset by the utility rate structure, which may pay a premium to buy the electricity from the vehicle battery during on-peak high demand situations. Finally, the societal benefit of V2G capable cars, in terms of reduced generation investment and reduced emissions, should be analyzed.

The priority for research in this area is first to ensure that the batteries are capable of additional cycles through V2H, which will likely occur before V2G. In V2H, the vehicle battery would provide emergency backup on rare occasions to the home in order to provide short-term necessary backup power. In order to progress first to V2H, there needs to be standard safety measures taken to protect both the users and utility workers. The added wear of V2G on the batteries should not be taken lightly, and regular, peak-shaving opportunities that are often discussed as a benefit of PHEVs would add significantly to the wear on the batteries. V2G may come about in the long-term but is not necessary for the success of PHEVs, nor would it provide significant benefit for consumers or utility operations until PHEVs are in widespread operation to act in a large controllable distributed-generation capacity for the electrical grid.

The research needs and opportunities for infrastructure research are shown in Figure 4–4 and the corresponding Table 4–6, which lists the research tasks identified on the timeline.

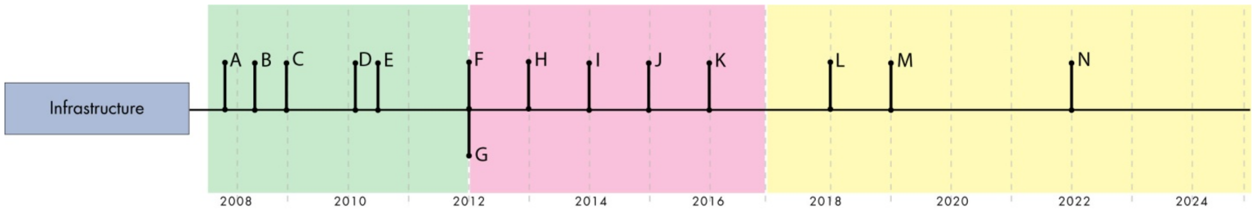

Figure 4–4. Infrastructure public interest research timeline

Item	Year	Research Task
A	2008	Research esisting EV TOU response
B	2008	Develop 2nd use business case
C	2009	Research requirements for successful V2H and charge timing, etc.
D	2010	Research cost, locations and requirements for public charging
E	2010	Develop effective TOU rates
F	2012	Test regional smart grids
G	2012	Smart meters implemented in California, test integration with vehilces
H	2013	Investigate charging solutions for multi-unit dwellings
I	2014	Develop safe disconnect systems for V2H
J	2015	Establish compatible communication protocols for vehicle and grid
K	2016	Develop economical widespread safety features for V2G
L	2018	Develop effective V2G electricity rates
M	2019	Develop strategies and solutions for paying for energy use outside of home utiltiy (third party?)
N	2023	Develop solutions to pay utility company directly for use when traveling

Table 4–6. Infrastructure public interest research task list

4.6. Consumer Behavior Research

4.6.1. Current Range of RD&D Activities

The following sections describe the types of research into PHEV consumer behavior and the potential market for PHEVs that are being conducted by other institutions.

Department of Energy

While the draft DOE R&D plan specifically notes that "it is too early to conduct PHEV market studies," the DOE, through its electricity division, gave an award to PNNL and the University of Michigan to conduct market and consumer research. Researchers at the University of Michigan Transportation Research Institute will conduct a survey as part of the University of Michigan Survey of Consumers and link it to trends in consumer demand from 1980 to the present.

DOE has issued an RFP for an OEM to developed and deploy 80 PHEVs, with awards up to $10 million per year for three years. The RFP does stipulate some study of driver response to the vehicle. These awards will be announced in summer 2008. The Idaho National Laboratory conducts extended testing of vehicles and surveys of fleet use of new vehicles, with minor attention to drivers, primarily driver travel behavior. The DOE Freedom Car Program has conducted isolated survey questions on PHEV demand.

Original Equipment Manufacturers

All OEMS interested in PHEVs are likely conducting market and consumer research. However, consumer research is normally the most competitive and proprietary information for auto manufacturers, and they do not share this information nor what sort of research they are conducting. However, OEMs do develop cooperative demonstrations for advanced environmental vehicles, with some allowance for partners to conduct some types of consumer research when the knowledge gained is for public planning, and do not give away competitive knowledge.

Toyota has developed 10 PHEV-10 Priuses, two of which will be placed in California, one at UC Irvine and one at UC Berkeley, for test and demonstration purposes. Eight vehicles have been kept in Japan, and their deployment not specified. The purpose of the vehicle is not fully specified; however, Toyota and the universities have said they are studying driver responses to the vehicle. Toyota has announced plans to deploy many more vehicles to California for demonstration in 2009.

Ford is developing 20 PHEV Ford Escapes, which are being deployed to Southern California Edison for testing and demonstration. It has not been specified what sort of consumer studies are being conducted; most of the vehicles will be deployed in Edison's own fleet.

South Coast Air Quality Management District

The South Coast Air Quality Management District has planned public demonstrations of PHEV conversions and has not announced specific consumer studies, but district representatives have talked with the PHEV Research Center about coordinating consumer studies. SCAQMD's original project plan included the conversion of 30 vehicles from hybrid to plug-in hybrids, including 20 Ford Escapes, and 10 Toyota Priuses. It included an intensive application and review program to evaluate the potential company that would be doing the vehicle conversions to ensure their safety and functionality.

EPRI

In 2002, EPRI conducted focus group and survey work on PHEVs. EPRI has expressed interest in studying consumer response to TOU-based electric rates.

Utilities

Southern California Edison is working together with Ford on a demonstration project. See discussion above in OEM section.

Universities

The University of Michigan is conducting consumer survey research, as described in the Department of Energy section above.

UC Davis is conducting several studies as part of the PHEV Center and for the Air Resource Board, which use converted vehicles, online surveys, and special studies of instrumentation. Specific projects assess the driving and charging patterns of PHEV drivers, the effects of energy use (electricity and gasoline) feedback on driving, choices to use electricity or gasoline, desired PHEV characteristics, and most important, the interrelationships among these. Total and time-of-day electricity demand to recharge PHEVs will significantly affect overall vehicle energy use and emissions of PHEVs as well as operation of the electric grid. The center will examine many aspects of the as yet little-studied consumer perspective on PHEVs and provide guidance to policy makers, utilities, car manufacturers, and the public.

The ongoing research being conducted on consumer behavior related to PHEVs is shown in Table 4–7.

Consumer Research	Charging Patterns	Vehicle Attribute Valuation	Access to Charging	Purchase Demand	Impacts of TOU Rates	Policy & Incentives
DOE/National Labs	NREL			ANL		
OEMs						
Universities	UC Davis	UC Davis	UC Davis	UC Davis, U of Michigan		
EPRI	EPRI	EPRI	EPRI	EPRI	EPRI	EPRI
Utilities	SCE	SCE	SCE, Progress Energy	SCE	Most	SCE, Most
ARB						
AQMDs						
Other						CalStart

Table 4–7. Ongoing research in consumer behavior areas

4.6.2. Gaps Analysis

At this point there are few programs focused on consumer response to PHEVs. (It is unknown what is going on inside of OEMs on this topic.)

Most of the public PHEV research on consumers has been the EPRI surveys and market analysis, which is now several years old. Other established programs are either relegated to simple survey work, which lacks sufficient context, or planned demonstrations with undeveloped consumer components. Most of these programs limit access to in-house fleet users for liability reasons and so are limited in their ability to explore general public response to the vehicles and lifestyle impacts of such vehicles.

One clear gap is that while the *State Alternative Fuels Plan* specifies adding 2 million public charging stations for PHEVs, there is no program studying how, where, and when to do this. Some stakeholders have stated that such infrastructure is costly and not needed for PHEVs.

Once a charging standard is developed, consumer studies need to determine the highest value location for public charging stations, so as to prioritize investments. Public infrastructure should be delayed until after a charging standard is developed to avoid funds being wasted on an infrastructure that may become obsolete after a standard is in place.

4.6.3. Stakeholder Meeting

The April 29, 2008, stakeholder meeting resulted in the greatest number of suggestions in the consumer area. In general, the stakeholder workshop focused on the need to quantify and identify the PHEV market, particularly as a function of gasoline prices, all electric range, and electric vehicle (EV) driving capability. The stakeholder meeting identified the following research topics:

- Study consumer response to charging opportunities, locations and distance of plug from parking, use in bad weather, work locations.
- Identify strength of various incentives to grow market and offset higher PHEV prices, including high occupancy vehicle (HOV) lanes, renewable electricity options, direct solar charging, and V2H systems.
- Study consumer response to mobile electricity opportunities.
- Study potential "geographical" segmentation of PHEV and EVs.
- Develop a "geographical information systems" approach
    - Based on regional differences in travel
    - Based on road systems
    - Based on existing, potential charging infrastructure
        - 120 volt network
        - 220 volt network
        - 440 volt 3-phase quick charge network
- Study potential of PHEVs in fleet markets.
- Benchmark and update previous PHEV studies.
- Test driver response to advance PHEV energy use instrumentation, compare consumer response to multiple interfaces, and study use of websites for PHEV driver experiences and energy use feedback.

4.6.4. PHRAC Feedback

The PHRAC suggested that the consumer research is one area of specialty that is of great value. One area the PHRAC suggested research would be useful is in measuring consumer response to TOU metering and rates, and the consumer response to the cost of TOU metering and charging equipment. In addition, a major concern for automakers and an area that would be valuable research is investigating the consumers' willingness to pay for a more expensive vehicle. Other research areas that were supported by the PHRAC were the driver response to advanced energy instrumentation on-board the vehicle, and response to mechanisms and programs that would control or limit in some way the time or duration of charging. Finally, the PHRAC suggested that real driver charging profiles, which would be used to model PHEV impacts and benefits, would be a useful area of research.

4.6.5. Key PIER Opportunities

Over the course of the three PHRAC meetings, the topic of consumer research has received more attention than any other research area. Recently in the news, Toyota has commented that their biggest remaining concern about PHEVs is the cost of the vehicle and therefore potential demand. It estimates that a PHEV will cost $5,000-10,000 more than a conventional hybrid. Of course, many new products cost much more, and some packages, like the navigation/Bluetooth package, on the conventional Prius costs about $5,000; so such extra costs are not "out of this world" in the market, and PHEV technology might have much greater benefits and appeal than navigation systems. The following are areas of research opportunities related to consumers and PHEVs:

California utilities are replacing current meters with smart meters that can deliver real-time rate information to PHEV owners. It will be useful to test consumer response to smart meters in the various studies and PHEV demonstrations in California. The meters may also allow for additional demand response opportunities for the utilities. There is a need to evaluate the possible integration of smart meters and PHEVs with existing demand response research and programs.

EV drivers in California have been offered special time-of-use rates to encourage off-peak charging. PHEVs are different from EVs in that their charging demands are smaller, and drivers are not completely dependent on electricity for driving. Together with smart meters, participants in PHEV demonstrations and studies offer a unique opportunity to test consumer response to these TOU rates, to explore whether consumers would be more responsive to a second meter, and how to best educate PHEV drivers about rate structures that may affect them. In particular, there will be a need to explore how responsive PHEV drivers will be to "off-peak" charging costs, i.e. will rates like $.34 per kWh be high enough to discourage on-peak charging, and will businesses and other locations that might offer opportunity charging be discouraged at such rates, and will discouraging on-peak charging adversely affect the market for PHEVs. PHEV demonstration projects may be the only context in which to observe response to TOU rate contingencies.

PHEVs are a unique vehicle in terms of their dual fuel use, energy characteristics, and variable benefits according to consumer use patterns. Essential to understanding potential PHEV benefits will be to study consumer response to advanced energy instrumentation for PHEVs. Such instrumentation will entail real-time electricity and liquid fuel consumption, costs and accumulated cost, and energy use feedback to the driver. Not only does such instrumentation affect use patterns, such as charging and driver behavior, but feedback from the instruments becomes part of the value proposition of the vehicles. Research should both create such instruments, test instruments, and test consumer response to such instruments.

Given the expected high price of PHEVs, it will be important to develop better methodologies and ways of simulating PHEV markets so as to study what prices consumer will pay for various types of PHEVs. Better understanding of PHEV markets and adoption rates in particular will be critical for utilities in preparing for the additional load and educating consumers about ways to mitigate the additional load of PHEVs.

Another aspect of commercialization of PHEVs will be the development of "pioneer" communities, that is early adopters, and especially websites devoted to the PHEV driver community. Research is needed that both experiments with adopter network effects and interacts with the broader car buying community.

Consumer satisfaction with 120-volt charging that is on-board current conversion PHEVs and will likely be the standard charging voltage for early PHEVs in the market must also be evaluated. This would include studying the impacts of slightly slower charging, as well as the ease of having the charger on-board and readily available power for 120-volt charging. These studies would likely compare customer satisfaction with 120-volt charging in comparison with 240-volt charging, and look forward to the possibilities for "fast" or "quick-charging."

The research needs and opportunities for consumer behavior research are shown in Figure 4–5 and the corresponding Table 4–8.

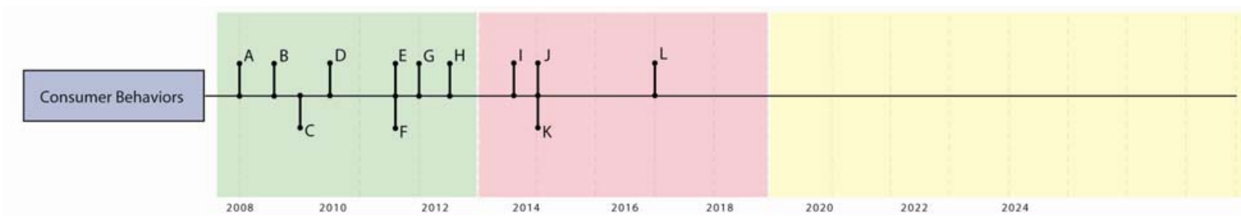

Figure 4–5. Consumer behaviors public interest research timeline

Item	Year	Research Task
A	2008	Consumer PHEV use study launch
B	2008	Define current consumer knowledge of HEV/PHEVs
C	2009	Study willingness to pay for PHEV technology
D	2009	Identify potential market for PHEVs
E	2010	Encourage modible electricity markets through enabling technologies
F	2010	Identify optimal consumer incentives
G	2010	Study consumer interest in emergency V2H
H	2011	Understand charging behavior
I	2012	Study customer response to TOU rates
J	2013	Develop PHEV CO2 feedback website
K	2013	Test driver response to advanced PHEV energy instrumentation
L	2015	Study consumer interence in V2G

Table 4–8. Consumer public interest research task list

4.7. Codes and Standards

The codes and standards section includes vehicle emissions certification, electrical code requirements for charging outlets, plug standardization, and communication protocols for PHEVs that would enable grid-vehicle communications. PHEVs present a unique challenge for emissions testing and certification due to the varied operating modes and possible control strategies. The emissions from these vehicles will be different in their charge-depleting mode compared to their charge-sustaining mode, and a vehicle with an all-electric range will have different emissions characteristics than a blended-mode operating strategy. Because of this, the standard short drive cycle that is used to characterize conventional vehicles is not an accurate representation of the emissions of a PHEV.

4.7.1. *Current Range of RD&D Activities*

Currently, the only facility that is known to be working on an emissions test procedure for PHEVs is the Department of Energy, at Argonne National Lab.

The Air Resources Board is very interested in understanding how to measure and certify vehicle emissions and may require a different test or calculation for vehicles sold in California.

Department of Energy

The DOE and Society of Automotive Engineers (SAE) have embarked on a PHEV Certification strategy, in cooperation with the EPA and ARB, but it is likely that California will have some of its own certification considerations. The DOE tests vehicle emissions at their Advanced Power Train Research Facility at Argonne National Laboratory. Their tests are performed on a four-wheel dynamometer in a controlled environment. DOE tests vehicle performance and fuel economy as well as emissions.

The DOE also has members participating on the Society of Automotive Engineers team to adapt a standard communication protocol for grid-vehicle communication.

Air Resources Board

The California Air Resources Board held workshops in spring 2008 on certification needs for PHEVs.

Below, Table 4–9 shows the institutions with on-going research related to PHEV codes and standards.

Codes and Standards	Vehicle Emissions Testing Protocols	Plug and Outlet Standards	CA Vehicle Certification	Grid-Vehicle Communication Standards
DOE/National Labs	ANL			
OEMs	Many (via SAE)	Ford, GM, Toyota, others	Many (via SAE)	Ford, GM, others
Universities	UC Irvine, UC Riverside			
EPRI	EPRI	EPRI		EPRI
Utilities		Most		SCE, PG&E, SDG&E, Most others (IWC)
ARB	ARB		ARB	
AQMDs			SCAQMD	
Other	SAE, EPA, DOT	NEC, IWC, SAE		Google, IEEE, IWC, SAE

Table 4–9. Ongoing research in codes and standards area

4.7.2. *Gaps Analysis*

There are few research institutions working on developing an emissions test protocol for PHEVs. The work that is being conducted by DOE with SAE will likely concentrate on meeting US requirements. While California has stricter emissions regulations, the process for testing vehicle emissions will likely be the same as the national test. There may be additional research for meeting California's regulations. In addition, there are so few institutions working on the certification issue that there may not be a choice for the "best" test protocol.

Importantly, the different vehicle architectures, control strategies and consumer behavior issues create a complex potential set of outcomes. Additionally, the test protocol for the U.S. emissions limits may only take into account the vehicle tailpipe emissions, whereas California may decide to take into account the additional emissions from electricity use in the vehicle. A test protocol that is over a certain distance, for example 100 miles, may be sufficient, but the accuracy should be compared to an emissions test that looks at the emissions in the two modes, charge-depleting and charge-sustaining, and average miles driven in each mode annually. In addition the expense of testing PHEVs for lengthy distances, while it may be more accurate, may prove to be prohibitively costly. Significant research must be done to insure that researchers have the most accurate emissions test protocol possible, without locking out certain technologies due to their control strategies.

Workshop stakeholders commented that there were three areas to add to the research concerns.

- Need to mitigate hazards of "quiet" cars to seeing impaired.
- Need to work on PHEV fuel economy sticker, ENERGY STAR® ratings and other consumer friendly information.
- Need to develop a "utility" weighting factor specific to California.

4.7.3. PHRAC Feedback

The PHRAC has not yet suggested or identified any additional research questions that would be a high priority in the codes and standards area.

4.7.4. Key PIER Opportunities

Due to the limited number of participating research institutions developing and testing emissions certification test protocols, there is plenty of opportunity for research into the best methods. The leaders in emissions test protocols for PHEVs, DOE and SAE may lead to a US test procedure that is unsatisfactory to the California Air Resources Board. If the electricity use is taken into account, the emissions from the regional electrical grid will have an impact on the vehicle emissions rating, which is difficult to track and certify. If electricity use is not included in the test procedure for emissions certification, it will not be an accurate representation of the emissions from driving PHEVs.

The research needs and opportunities for codes and standards research are shown in Table 4–10 and the corresponding Figure 4–6.

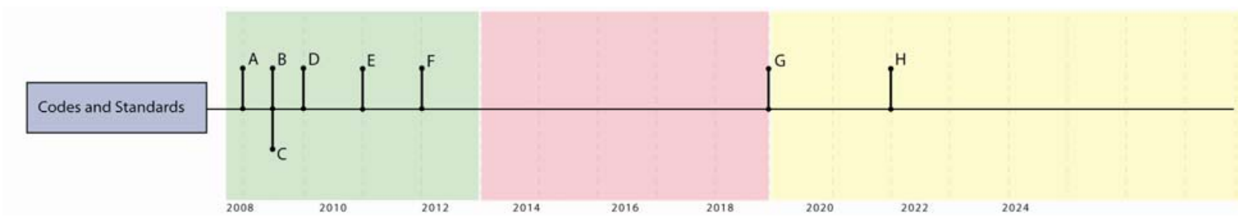

Figure 4–6. Codes and standards public interest research timeline

Item	Year	Research Task
A	2008	Define informational needs for proper certification
B	2008	Develop SAE PHEV emissions testing standard
C	2008	Develop plug standards and codes and safety evaluation
D	2009	Share use patterns and impacts with SAE emissions standards group
E	2010	Research ways to mitigate hazards of "quiet" cars to seeing impaired
F	2011	Develop PHEV fuel economy sticker, "Energy Star Rating", and other easy, consumer friendly energy use information
G	2017	Develop V2H communication standards
H	2019	Develop V2G communication standards

Table 4–10. Codes and standards public interest research task list

4.8. Environmental Benefits and Lifetime Costs

4.8.1. *Current Range of RD&D Activities*

The following sections describe the types of research into environmental benefits and lifetime costs of PHEVs that are being conducted by other institutions. A focus of PHEV research in this area is the comparative benefits of PHEVs and electricity to using gasoline. Complicating this is that the CO_2 emissions from each region in the United States varies considerably, especially between regions that have hydroelectric and nuclear, which are almost CO_2 free, to regions that are primarily coal-fired. Additionally, such models must compare different fueling technologies and pathways, for example, natural gas to hydrogen, or coal to electric drive. On top of this, analysis of PHEVs must consider the cost of the vehicle, the batteries, and the other infrastructure costs for PHEVs.

Department of Energy

The DOE, through its Argonne and National Renewable Energy Labs, has conducted a variety of studies examining the environmental benefits and costs of PHEVs.

Argonne National Labs has been the lead lab on much of this analysis, often in collaboration with EPRI. Argonne has developed the National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, which has been used by most teams to analyze lifetime emissions. They also maintain and distribute a number of other models used by researchers around the world to study costs and design.

Included in this category are studies that examine the potential of PHEVs to reduce petroleum consumption. Argonne has examined this, as well as NREL.

Original Equipment Manufacturers

The OEMs do some environmental analysis, but it is not their primary focus. OEMs do conduct cost studies, but this is often proprietary.

Universities

Environmental analysis is a strong suit of university researchers. UC Davis has the most developed program and most developed models of lifetime emission (LEM) and advanced vehicle cost and energy models. Several researchers are working on comparing the life cycle cost and emissions from petroleum, electricity, biofuels, hydrogen, and natural gas and their feedstocks for transport uses. UC Berkeley has done some modeling of PHEV benefits, as have the Massachusetts Institute of Technology and Carnegie Melon University.

EPRI

EPRI has coauthored with Natural Resources Defense Council a recent and extensive analysis of the potential greenhouse gas benefits of plug-in hybrids (and the impact of charging on the grid). This study "evolves" the grid to account for potential improvements in the system over time as the PHEV market develops.

Table 4–11 shows the institutions with current research in the field of environmental benefits and lifetime costs related to plug-in hybrid electric vehicles.

Environmental Benefits and Lifetime Costs	CO_2 Emissions	Criteria Pollutants	Water
DOE/National Labs	ANL, NREL, PNNL		
OEMs			
Universities	UC Davis, U of Michigan	UC Davis, UC Irvine, U of Michigan	UT Austin
EPRI	EPRI	EPRI	EPRI
Utilities			
ARB	ARB	ARB	
AQMDs	SCAQMD	SCAQMD	
Other			

Table 4–11. Ongoing research in environmental benefits and lifetime costs areas

4.8.2. Gaps Analysis

So far there has been limited work in the area of costs studies and modeling for PHEVs. Battery technology and manufacturing are changing rapidly, so research in this area will be of strategic importance and will need to reflect current events and technical opportunities.

Right now, there is not a single model that integrates the detailed, power plant by power plant (changing over time) level of analysis for electricity emissions (like the EPRI study) with the detailed cross comparison of transportation fuels pathways (like the GREET or LEM).

There needs to be research in the near future on devising a method for awarding credits in a cap-and-trade system, or other credit systems. Data acquisition systems in vehicles need to be developed, especially as related to the LCFS.

4.8.3. Stakeholder Workshop

A primary suggestion put forth at the stakeholder workshop was to rework this category and separate out the issue of "costs" as a general topic for PHEVs, given that cost of manufacturing (mainly batteries) stands as a significant hurdle to commercialization.

4.8.4. PHRAC Feedback

The PHRAC has not made any specific research suggestions for environmental benefits or lifetime cost research, noting that the environmental modeling is badly needed, but that several models are in development. The cost modeling is important given the projected high costs of PHEVs, but the PHRAC noted that most of the cost models developed by analysts outside the auto industry for vehicle development and manufacturing are not accurate, according to the major auto manufacturers. This is because most of the needed cost information is competitive business information.

4.8.5. Key PIER Opportunities

There is a lot of ongoing research in the area of understanding the environmental benefits and lifetime costs of advanced vehicles, including PHEVs. The most prominent emissions model is known as the GREET model, developed by ANL and widely used. There are additional models that seek to evaluate the emissions of PHEVs, including UC Davis' own LEM developed by Dr. Mark Delucchi. These various emissions models can be adapted to model region-specific emissions impacts or be used comparatively to validate their results. Additionally, each of these emissions models will need to be updated regularly to account for new information about PHEVs as it becomes available. These updates may include information on "real-life" consumer driving and charging behavior, the impact of smart meters and a smart grid, various rates of PHEV adoption in the marketplace, batteries used in second-life applications, and battery recyclability, as well as other variables.

The research needs and opportunities for environmental benefits and lifetime costs research are shown on Figure 4–7 and the corresponding Table 4–12, identifying research tasks on the timeline.

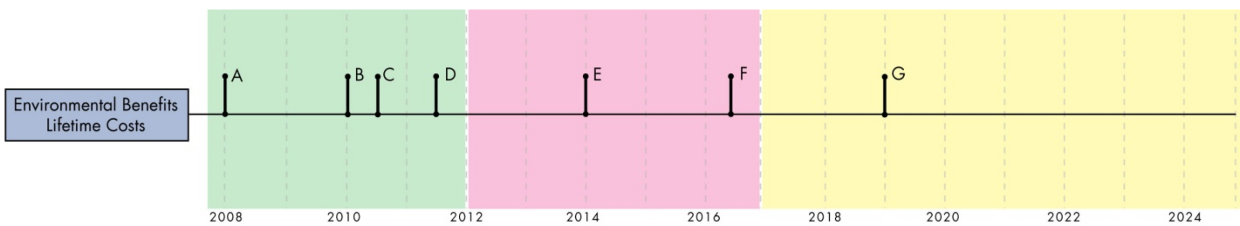

Figure 4–7. Environmental benefits and lifetime costs public interest research timeline

Item	Year	Research Task
A	2008	Evaluate what are the CO2 and materials impact of PHEVs based on consumer use and various architectures (including powertrain and battery size)
B	2010	Evaluate what are the impacts of 2nd life and recycleability of batteries (on labor, toxicity, energy inputs, sources, energy security, and green jobs)
C	2010	Research how to measure and award carbon credits. Can this be done in a way to encourage certain driving/use behaviors?
D	2011	Study impacts of V2H and V2G
E	2014	On-going efforts to continually update and add "modern" fuel properties to models
F	2016	Input results of V2G tests on local grid
G	2019	Calculate changing benefits of PHEV use

Table 4–12. Environmental benefits and lifetime costs public interest research tasks

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Glossary of Terms

AAA	American Automobile Association
AB	Assembly Bill
AER	All-electric range
ANL	Argonne National Laboratory
ARB	California Air Resources Board
BEV	Battery electric vehicle
BYD	Build Your Dreams (a Chinese automotive battery and vehicle company)
CO_2	Carbon dioxide
CPUC	California Public Utility Code
(US)DOE	(United States) Department of Energy
EISA	Energy Independence and Security Act
Energy Commission	California Energy Commission
ENVI	Chrysler's Environmental Vehicle Group
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
EREV	Extended range electric vehicle
EV	Electric vehicle
FCVT	FreedomCar and Vehicle Technologies (a USDOE program)
GGE	Gasoline gallon equivalents
GHG	Greenhouse gas
GM	General Motors
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
G2V	Grid-to-vehicle
HEV	Hybrid electric vehicle
HOV	High occupancy vehicle

H.R.	House of Representatives (used for bill numbers)
ICE	Internal combustion engine
IEPR	*Integrated Energy Policy Report*
INL	Idaho National Laboratory
kW	Kilowatt
kWh	Kilowatt-hour
LADWP	Los Angeles Department of Water and Power
LCFS	Low-Carbon Fuel Standard
LEM	Lifecycle Emissions Standard
Li-ion	Lithium-ion
MPG	Miles per gallon
NEC	National Electric Code
NiMH	Nickel-metal hydride
NRDC	Natural Resources Defense Council
NREL	National Renewable Energy Laboratory
OEM	Original equipment manufacturer
ORNL	Oakridge National Laboratory
PG&E	Pacific Gas and Electric Company
PHEV	Plug-in hybrid electric vehicle
PHRAC	PHEV Research Advisory Council
PNNL	Pacific Northwest National Laboratory
R&D	Research and development
RD&D	Research, development and demonstration
RFP	Request for proposal
Roadmap	This paper, *Plug-In Hybrid Electric Vehicle Research Roadmap*
SAE	Society of Automotive Engineers
SAFP	*State Alternative Fuels Plan*

SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric Company
SMUD	Sacramento Municipal Utility District
TAC	Technical Advisory Committee
TARP	Troubled Asset Relief Program
TOU	Time-of-use
UCD	University of California at Davis
USABC	United States Advanced Battery Consortium
VW	Volkswagen
V2G	Vehicle-to-grid
V2H	Vehicle-to-home
ZEV	Zero emission vehicle

Appendix A: Review of Literature and Research Programs

In March 2007, the PHEV Research Center undertook a review of research programs, such as that of the Department of Energy who has been concurrently in its own research and development plan process, as well as those at EPRI, and the utilities. Additionally, the center director visited several utilities and U.S. Department of Energy R&D planning sessions, and made a presentation on the new center at Argonne National Labs, the lead lab for plug-in hybrid electric vehicle (PHEV) research. This review was developed into a PowerPoint® presentation for the initial PHEV Research Advisory Council meeting.

There are a number of recent reports on the status of PHEVs. The following is a short review listing the promises and challenges of PHEVs discussed in some documents. This is not comprehensive, rather is a summary of the most important points raised by major groups of researchers. This set of summaries is included here to point out the primary research questions being identified in recent studies.

Draft DOE R&D Plan (February 2007)

Benefits

- PHEVs can reduce oil dependence.
- They are an enabling technology for renewable energy in electric power sector.
- There appears to be plenty of grid electricity in the near-term and mid-term.

Challenges (more details in gaps section)

- Challenges include high cost, durability, and size (packaging) of batteries.
- Cost of battery for a full power PHEV 40, and cost of two full drive trains is very high.

DOE Freedom Car & Vehicle Technologies Program

(February 2007 Draft) Plug-In Hybrid Electric Vehicle R&D Plan

The DOE program on PHEVs is larger and more comprehensive than anything the PHEV Research Center could develop. But the DOE program is technical R&D-oriented and is shaped by certain assumptions. Researchers go over this program in more detail, to look at its assumptions, programs, and sensibilities to find strategic gaps, opportunities for collaboration and specialization of the PHEV Center. Below is a list of central points from the draft PHEV research plan.

Results of May 2006 Two-Day DOE Workshop (page 3)

- PHEVs can substantially reduce petroleum consumption.
- Electric power efficiency and environmental impact of vehicles can be improved by shifting to electricity.

- Off-peak generation can handle a large number of vehicles – power from grid is not a barrier.
- Cost is primary impediment.
- Battery technology is potential show stopper.
- Fuel economy rather than all electric range is the key vehicle efficiency metric for the public.
- All other vehicle aspects must be competitive, including purchase and operating costs.
- AER requirement would drive up cost and decrease likelihood of production.
- Federal government is expected to set policy, support pre-competitive research, act as trusted source of information, and minimize market barriers for PHEVs.

FreedomCar and Vehicle Technologies (FCVT) will proceed with a R&D plan for PHEVs

- Based on possible petroleum reductions from PHEVs, but it is premature to assess market potential.
- FCVT plans a rigorous analytical approach to determine key attributes of PHEVs and quantify the value proposition.
- FCVT has ongoing activities to develop batteries, power electronics, and electric machines that are applicable to PHEVs.
- PHEVs are still in development phase, and designs range from full-power electric to evolutionary steps from hybrid only designs (a family of options).
- Higher power and energy electric propulsion systems cost more (40 miles of AER requires tenfold increase in energy storage over today's hybrids).
- Electric drive power will have to double for full speed in both AER and hybrid modes.
- Therefore, there is no solution for PHEVs without a breakthrough in cost reductions.

Research challenges:

- Li-ion batteries: (Office of Science advance materials development activities)
- Developments targeting cost reduction (materials and processing; cell and module packaging)
- Improved specific energy
- Life and abuse tolerance
- Power electronics and electric machines
- Cost reductions
- Volumetric reductions
- Vehicle efficiencies
- Low cost, lightweight materials
- Efficient ancillary systems (heating, air conditioning)

- Grid interactions: (Office of Electricity)
- Vehicle –utility interface
- Regional impact analysis

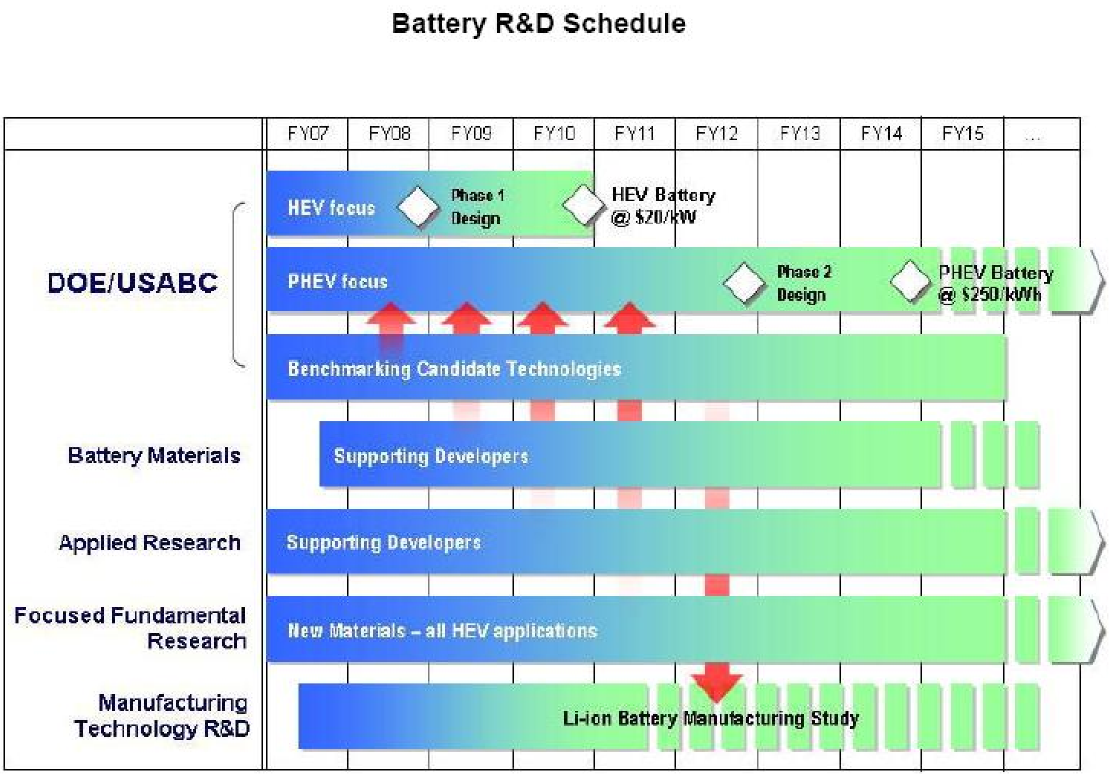

Figure A–1. DOE battery R&D schedule

Credit: U.S. Department of Energy, February 2007

- Vehicle modeling and simulation software
- Standard battery bench testing: PHEV specific procedures
- Battery hardware in the loop (HIL)
- Higher power
- Faster emulator
- Vehicle dynamometer testing: PHEV specific procedures
- "Activity is underway to identify the needed changes to standard test procedures and protocols to measure and report fairly PHEV fuel economy"

Phased Development

- Near term: "adapted technology"; electric range of 10-20 miles (reduced performance); hybrid range of 20 miles
- Midterm (3-5 years): "PHEV specific designs", electric range of 20 miles or more and blended range of 40 miles
- Long-term (5-10 years): components to meet the 40 mile all-electric range

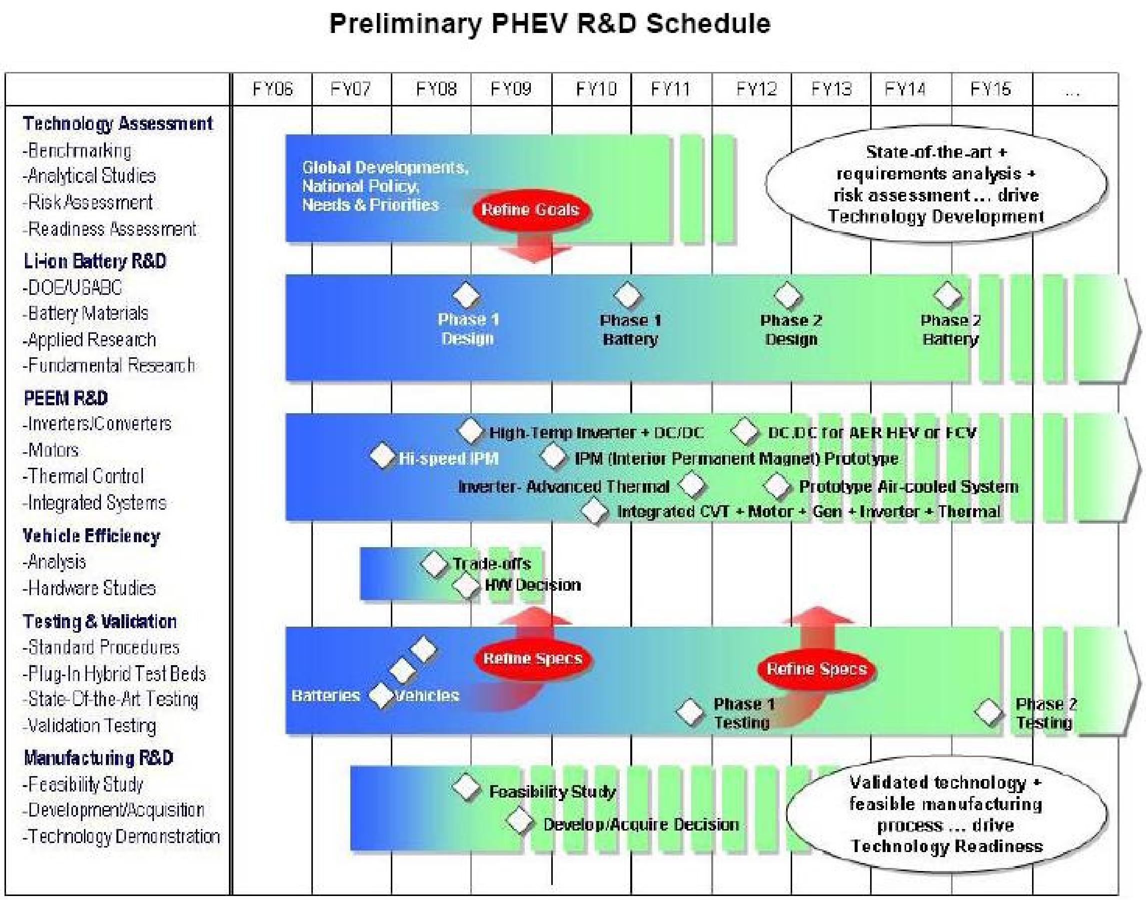

Figure A–2: DOE preliminary PHEV R&D schedule

Credit: U.S. Department of Energy, February 2007

Development Strategy

- Two generations of technology development are proposed:
    - First generation 06-07 – adaptation available tech / 08 batteries
    - Second generation: 09-10 – specific PHEV designs
- System integration, validation, demonstrations: National Labs will analyze, specify, integrate, test, and validate the battery and electric components in this process – up to 40 mile PHEV.
- A solicitation for 10-20 vehicles in 3-5 cities for 2008-2010
- Development and demonstration of manufacturing technology for Li-ion.

Collaboration

- Industry: USABC on batteries; SAE on PHEV specific test procedures

- Gov: Office of Electricity; (power generation and distribution); Office of Science (materials R&D); biomass program (ethanol); EPA: test procedures for emissions; National Institutes of Standards and Technology manufacturing technologies
- Academia: Currently DOE works with 12 universities on fundamental battery research

	Analysis	Batteries	PEEM	Vehicle Efficiency	Facilities
Argonne	• Technology assessment • Risk assessment • Vehicle modeling and simulation • Well-to-wheels energy/emissions • Agent-based behavior modeling • Macroeconomics modeling	•Standard protocols, benchmarking, validation •Applied R&D; accelerated aging and diagnostics •HIL testing	• Benchmark testing • HIL testing • System integration & control • Capacitor development	• Trade-off studies • Hardware studies	•Advanced Battery Test Facility (ABTF) •Advanced Lithium Battery R&D Facility •Advanced Powertrain Research Facility (APRF)
INL Idaho National Laboratory		•Standard protocols, benchmarking, validation •Applied R&D; accelerated aging and diagnostics	•Vehicle/charger interface and testing		•Advanced Vehicle Testing Activity (AVTA) •Energy Storage Technology Laboratory (ESTL)
Berkeley Lab		•Long-term R&D; materials and electro-chemical couples			•Advanced Battery R&D Facility
NREL	• Synergy with renewable energy sources	•Thermal analysis	• Component & system thermal testing, modeling and analysis		•Thermal Management Test Facility
Oak Ridge National Laboratory	• Regional grid analysis • Policy analysis		• Research, design, modeling, testing, evaluation and analysis: -Inverters and dc-dc converters -Electric motors -Thermal control -Benchmarking		•Power Electronics & Electric Machines Research Center (PEEMRC) •Fuels, Engines and Emissions Research Center (FEERC) •Hi-Temperature Materials Lab (HTML)
PNNL	• Regional grid analysis				•Exhaust Chemistry and Aerosol Research Center (ECAR)
Sandia National Laboratories		•Cell, module and battery abuse testing	• Regional grid analysis		•Battery Abuse Testing Facility

Figure A–3. DOE table of research at National Labs
Credit: U.S. Department of Energy, February 2007

Final ZEV Staff Report (April 2007)

Benefits

- Incremental cost can be offset by low operating cost, i.e., electricity prices.
- Offer direct societal benefits (GHG emissions, zero emissions in cities).
- Major technical issue is number of deep cycles battery can sustain; number needed is not known.

Challenges

- Test procedure for PHEV emissions and efficiency do not exist; prior assumptions consider PHEVs with AER; blended designs now a focus of development. (Current ARB regulation invites manufacturers to offer their own procedure for their design).
- Cost of greater range is not well understood.
- No OEM planning to make a commercial PHEV until 2010 or later.
- Uncertainly exists as to how PHEVs will be used across their life. Will they be plugged in consistently and evenly across their life? Will electricity use be maximized across a wide variety of driving cycles (or from a consumer perspective, lifestyles)?

Update to ZEV Mandate (Nov. 2007)

- The ZEV mandate update allows PHEVs to be used to meet ZEV credit requirements for automakers. They are allocated a higher credit if they have an all-electric range certification compared to blended mode strategies. The credit increases with increased all electric range. ARB has proposed changing from credits based on AER to credits based on equivalent AER, wherein equivalent AER takes miles driven in charge-depleting mode and then adjusts those miles to a percentage of those miles operated electrically. They also proposed that the credit allowance be adjusted by a utility factor to normalize the credit allowance to a maximum of that earned by a city electric vehicle.
- These rules and regulations are still under debate as to the best way to achieve the goals of a cleaner, less petroleum-dependant transportation system in California, but ARB is beginning to take into account the various modes by which a PHEV may operate and include that in the regulations. Additional changes may occur based on the types of vehicle architectures and control strategies proposed by early makers of PHEVs. (EPA 2007)(from a presentation by D. Chartier, M. Shelby, S. Mui, D. Ganss)

Benefits

- Possibility of significant GHG emissions reductions via PHEVs over 20 to 30 years
- Complementary electric sector GHG reduction technologies, e.g., peak shaving and integration with intermittent sources such as wind
- Large potential petroleum consumption and oil import reductions
- "Game changing" technology to shift fuels to electricity sector

- Electric fuel costs equivalent to $.60 per gallon
- No need for new large fuel infrastructure

Challenges

- High upfront costs for PHEVs; Li-ion batteries 3,000-5,000 in near to mid term
- Additional vehicle costs because of two drive trains
- Problems with durability and performances
- Consumers may not have access to garages, some need to add electrical circuits
- Availability of off-peak pricing
- Problems with resale value?

International Energy Agency “Global Prospects of Plug-In Hybrids” (Oct. 2006)

(A collaborative paper by international panel of experts in the IEA Hybrid Implementing Agreement)

Benefits

- Can create a more electric pathway to sustainable consumption.
- Can reduce imported oil.
- Creates mechanism for consumer to switch from oil to electricity, thus mitigating oil price shocks.
- European government studies have shown that a PHEV with 100 km of range could use electricity for 85% of driving. EPRI shows 64-74% of miles could be electric (grid)
- Nighttime charging of PHEVs could make electric power more “efficient” filling diurnal and seasonal troughs in power generation demand.

Challenges

- PHEV batteries face worse lifetime problems than BEV or HEV batteries.
- Based on survey work, a 2002 EPRI study notes that need to replace battery pack in PHEV at midlife reduces market share from 33% to 17%.
- In same market analysis, PHEV 20, because of its lower cost, shows much higher market share than PHEV 60.
- Charging costs: economical slow charging of smaller battery PHEV overnight (just over $400) more marketable than fast, one hour charging equipment ($1,000).
- Batteries will be Li-ion, but uncertain if state-of-charge window in Li-ion is bigger than NiMH, but some optimism here.
- Consumer preference: environmental preference is low (this is changing); but preferential electric rates improve consumer preference,

- Availability of charging varies across Europe and U.S. regions (50% in Europe in garage; 50% not). Certain countries may have significantly better (Sweden may be up to 70%) or worse (France may be as low as 20%) access to charging, although it is higher outside of the major cities.

Appendix B: PHRAC Review and Feedback on Research

First Advisory Council Meeting

May 2007

The first advisory council was held in May 2007 at UC Davis. It was attended by all council members and chaired by Energy Commission Vice Chair James Boyd. The PHEV Director Tom Turrentine and PHEV Center Manager Dahlia Garas presented the review of research programs, soliciting comment from the PHRAC. Given the breadth of potential research topics, this first meeting was necessarily broad, but council members graciously debated the full range of potential directions the center could take.

Additionally, UC Davis researchers discussed their first year projects, which were awarded in advance of the Roadmap Process. These included Dr. Kurani's Consumer Research, Dr. Burke's Battery and Systems Research, and Dr. Delucchi's Environmental Lifetime Emissions Modeling.

In Attendance:

Chair: Energy Commission Vice Chair Jim Boyd

Ed Wall, DOE

Ed Kjaer, SCE

Dean Taylor, SCE

Philip Misemer, Energy Commission

Andreas Truckenbrodt, DaimlerChrysler

Bill Boyce, SMUD

Mark Duvall, EPRI

Matt Miyasato, SCAQMD

Jill Egbert, PG&E

Peter Ward, Energy Commission (Adv. to C. Boyd)

Martha Krebs, Energy Commission

Toshio Hirota, Nissan

Brian Johnston, Nissan

Laurie ten Hope, Energy Commission

Alex Kim, SDG&E

Dahlia Garas, PHEV Center

Tom Turrentine, PHEV Center

Ken Kurani, UC Davis

Andy Burke, UC Davis

Mark Delucchi, UC Davis

The output of this 1st meeting was the following list of research suggestions.

Suggested R & D distilled from first Plug-in Hybrid Advisory Council Meeting:

1. PHEV Batteries:
    a. Research and development of potential second-use market applications of used PHEV batteries.
    b. Research and development of battery temperature management approaches and effects of temperature management on battery life/performance.
2. Lifecycle environmental modeling
    a. Research real world consumer charging behaviors and develop a charging profile based on real-world data for use in modeling efforts.
    b. Develop lifecycle cost modeling that is an accurate representation of actual OEM manufacturing and industrialization costs.
    c. Research to incorporate battery manufacturing methods and costs to improve life cycle modeling analysis
3. Recharging infrastructure
    a. Research data acquisition and timer systems at the plug for PHEVs.
    b. Research possibilities for vehicle-to-home and vehicle-to-grid requirements (compatible communication, power etc.) and applications.
    c. Evaluate possible synergies between PHEVs and renewable power sources.
4. Consumer PHEV use and choice behavior
    a. Develop method or system for acquiring driving data from vehicles in order to understand real-world consumer driving and charging data.
    b. Research into vehicle energy information feedback systems. (What information is useful and effective?)
    c. Evaluate consumer buying habits and choices. (How much are consumers willing to pay for advanced vehicles, or for certain benefits of an advanced vehicle?)
    d. Research into how to better educate the consumers and improve consumer knowledge, awareness and expectations of PHEVs.
5. Codes and Standards
    a. Certification needs did not get discussed, as time ran out on the first meeting. This list was sent out to the PHRAC, and additional suggestions were solicited and appended to the list above.

Second Advisory Council

August 21, 2007

The Second Advisory Council Meeting was held Aug 21, 2007, at the Marriot Hotel in Monterey California (in proximity to the Biennial Asilomar Conference on Transport Energy and Climate Change).

In Attendance:

Chair: Energy Commission Vice Chair Jim Boyd

Phyllis Yoshida, DOE

Ed Kjaer, SCE

Philip Misemer, Energy Commission

Andreas Truckenbrodt, DaimlerChrysler

John Tillman, VW

Steve Plotkin, ANL

Efrain Ornelas, PG&E

Bill Boyce, SMUD

Mark Duvall, EPRI

Matt Miyasato, SCAQMD

Susan Brown, Energy Commission (Asst. to C. Boyd)

Toshio Hirota, Nissan

Brian Johnston, Nissan

Laurie ten Hope, Energy Commission

Dahlia Garas, PHEV Center

Tom Turrentine, PHEV Center

Jill Egbert, PG&E

Peter Ward, Energy Commission (Adv. To C. Boyd)

Suggested R & D distilled from second Plug-in Hybrid Advisory Council Meeting:

At the 2nd PHRAC, council members were presented with the suggested topics above, and the Director Turrentine worked with the council to consolidate topics, expand content and focus on the most strategic goals of the center. At least three primary focal areas emerged from the meeting.

1. On the primary area of batteries, council members emphasized research on batteries that focused on the potential reuse of PHEV batteries in stationary applications, both technical and business aspects of that reuse.

2. On the primary area of vehicle architecture there were no further strategic areas of concern
3. On the primary area of environmental modeling, it was concluded that major modeling work at other labs was already funded and well-developed.
4. On the primary area of consumer research, several of the topic areas of concern are well-funded, but several topics are of strategic need and are discussed further, including vehicle-to-home, vehicle instrumentation, and consumer demand for PHEV attributes.
5. On the primary area of impacts on utilities and the grid, it was concluded that major efforts by other research groups had covered this topic well.
6. On the primary area of codes and standards certification, the PHRAC ran out of time again before careful consideration of this topic. The director will make efforts to bring this topic to the PHRAC through other mechanisms.

Third Advisory Council Meeting

February 14th, 2008

In Attendance:

Vice Chair Jim Boyd, Energy Commission

Philip Misemer, Energy Commission

Peter Friebe, Daimler

David Lake, GM

Toshio Hirota, Nissan

Brian Johnston, Nissan

Lee Slezak, DOE

Mark Duvall, EPRI

Bill Zeller, PG&E

Dean Taylor, SCE

Joel Pointon, SDG&E

Bill Zobel, SDG&E

Matt Miyasato, SCAQMD

Sherif Marakby, Ford

Tom Turrentine, PHEV Research Center

Dahlia Garas, PHEV Research Center

Ken Kurani, UC Davis

Andrew Burke, UC Davis

Agenda:

1:00 – 1:15 Introductions from Tom Turrentine

1:15 – 1:35 Commissioner Jim Boyd on AB118

1:25 – 2:00 Dr. Burke: PHEV Performance: Simulation Results and Key Design Considerations

2:00 – 2:30 Dr. Kurani: Consumer Research Update and Early Survey Results

2:30 – 4:00 Roadmap Discussion and Input

4:00 – 4:45 Annual Research Plan and equests or roposal

4:45 – 5:00 Plug-In 2008 Conference Overview

Intro to AB 118 - $120M/yr to the Energy Commission, $80M/yr to ARB, jointly plan work with the Energy Commission and ARB:

AB 118 is encumbered with provisions that will make it slow to spend the money. ARB still must design and pass refining legislation defining how to regulate and implement the bill Minimum time before money will be available is 4-6 months, but it could be one year or more. It may not be possible to spend all the money the first fiscal year, although the Department of Motor Vehicles begins collecting the money in July, 2008.

Second encumbrance – need Advisory Committee for the Energy Commission to develop plan for spending the money. Certain people are required by the law, to be represented. People on the Advisory Committee and groups they represent can't get money, so they may decline the invitation to serve on the committee. There will need to be clean-up legislation to clean up the bill.

There is a concentration on demonstration and deployment efforts.

New Commissioner at the Energy Commission: Karen Douglas, attorney for Environmental defense, helped construct AB 118.

After Burke's presentation, asked that his paper be posted on the website.

Tom's timeline of the jump from 100's of demo vehicles to 10,000's of vehicles by 2012 seems too aggressive.

Discussion of Research Areas:

1. Batteries
2. Vehicle architecture and control systems
3. Environmental benefits and lifetime costs
4. Consumer demand and use patterns
5. Infrastructure impacts

6. PHEV Codes and Standards

DOE also is looking at risk assessment of manufacturability, recyclability, end of life

Possibly do some policy research and education.

Infrastructure

1. Does California have the infrastructure or power systems research to do significant research into infrastructure impacts? Who can do this kind of research on a timeline? This is one of the most resource impacted areas of research. There aren't enough specialists or recent graduates to fill the available positions and research needs in California or the country.
2. There is too much emphasis in the Research Roadmap on V2G, and not enough on V2H. Need to be realistic about probable outcome and timeline. Emphasize V2H and just controllable, commandable, programmable vehicle charging (G2V).
3. Characterizing full hybrids (existing) that may become PHEVs is a good idea. Also, need to look at emissions, Climate control especially is a huge energy loss, look at lowering energy losses from the accessories on-board.
4. May want to include a section on trends and drivers and discuss limits of resources affecting the technology, i.e. lack of educated engineers (in power controls/power electronics)

Vehicle Architecture

1. Characterize fuel strategies, dictating a control strategy (blended mode or AER, for example) or architecture doesn't work. Setting performance standards does work, in this case, emissions and fuel economy standards.
2. There is also a huge need for certification procedures, not just in light-duty vehicles, but in medium- and heavy-duty vehicles as well. Do many kinds of certification options so that OEM's can make all kinds of PHEVs. Don't want to close the door on a type of technology with a limiting certification procedure.
3. The ARB always worries about having a good product that is warranty-able and someone to support that warranty. Need to take that into account with PHEVs, especially concerning batteries.
4. We may need to pay special attention to medium-duty and heavy-duty applications. Work with the utilities, look at how to partner and structure research and demonstration efforts around medium-duty and heavy-duty vehicles.

Batteries

1. Taking into account the resource limitations of both the PHEV Center and California, will priorities emerge in the Roadmap eventually?
2. Perhaps to clear things up we should add more of a timeline context to the Roadmap in order to give some direction toward priorities.

3. Plan needs to build on scope of research and give insights into available resources. May include workshops, public hearings, and peer review for the Research Roadmap.
4. Lifecycle testing (of batteries) is a lower priority since many people are doing this. Other research areas (#'s 2, 3, 4 Vehicle Architecture, Environmental Benefits, and Consumer Research) are a higher priority.
5. Also need to look into the testing/certification requirements for transporting Li-ion batteries by sea and air. Right now, transportation of batteries is a major hurdle.
6. Look into other first use options for Li-ion (non-mobile) in order to increase production, decrease costs, and build the market for large format Li-ion batteries.
7. The second use applications may expand to other mobile applications such as golf-carts, lift-trucks, mobile homes, etc. First-use may not be exclusively mobile applications, and second-use may not be exclusively stationary applications. Look into other possibilities. Where do mobile and stationary applications overlap in requirements?

Environmental Benefits and Lifecycle Costs

1. There is a need for improved lifecycle assessment cost model.
2. Social cost models need to include CPUC at the table
3. Is there a user benefit model? A way to quantify the benefits of PHEVs so that the user doesn't perceive a net cost increase for PHEVs or even perceives a net benefit. Cost increase-payback-user benefits equal zero or greater. Quantify user inconvenience from having to charge. We look at user happiness after a customer, but we also need to look at what benefits will get them to be a customer in the first place. ORNL and University of Michigan are currently looking at this topic.
4. Continue to do cost models because companies won't share their costs. Even bad cost models at least encourage discussion about vehicle cost. Need to make the models as open as possible and involve as many external stakeholders as possible, and then allow people to use it and comment on it.
5. Talk to the suppliers about costs, not OEMs, and then apply a factor to get the OEM cost. (For example battery cell cost for a pack X 2 = OEM pack cost according to Anderman). OEM's may be able to give some feedback if "reasonable" assumptions were made in cost models.

Consumer Studies

1. AB 1007 has allocated $2Million for public charging infrastructure. Item 5 of AB 1007 had a lot of input from stakeholder groups that see PHEVs as a stepping stone to BEVs.
2. Need to keep BEVs in mind when thinking about charging infrastructure. The timeline for the Roadmap is long, and customer point of view will change, should include BEVs as part of progress.
3. Work and "other" charging locations may increase the market appeal and encourage buyers if charging is perceived as available.

Infrastructure

1. PHEV "Clusters" are a hot research area right now; EPRI is funding many projects in this area. How are clusters any different than a new subdivision or building? PHEVs are max 1.5 kW with 110V charging, so we've already had adoption of PHEVs in effect, just by everyone having plasma TVs at 500-800W.
2. Market Redesign Technology Upgrades make recommendations to CPUC on rate design related to use of smart meters, distributed resources. Should take their recommendations (which will affect economics, loads etc.) into account.
3. PG&E already requires PHEV drivers to be on a special TOU rate.
4. Some of these items and topics are in the Research Roadmap because we want to recognize them as part of our "PHEV world" but don't need to do research on them (like PHEV clusters if EPRI is already funding research projects in this area).
5. What the auto OEMs would find most helpful is finding second use for batteries; the OEMs will manage the chain for batteries.
6. Need to look at a California transportation battery business case, as California PHEV Center.

Suggested Year 2 Research Topics

1. Battery Business Case
2. Battery second use scenarios
3. Battery recyclability
4. Consumers

Overall Comments

1. The first three suggested research areas for year two are battery specific, not PHEV specific. Suggest looking at the consumers of upscale vehicle producers. Look at performance differences once the battery is depleted. Specifically, look at consumer preferences and tolerance for reduced or changed performance.
2. There are so many differences between market forecasts of how many PHEVs there will be and when they will arrive on the market, adoption rates. Need some clarification of various market forecasts.
3. Suggest tailoring a survey toward what people experience and desire in performance, perception of the vehicle, perhaps classify the results by income, age, and other demographics.
4. Look at the performance difference in terms of meeting the fuel economy window. How much of a letdown is there if a car doesn't meet their fuel economy expectations. Since the difference in fuel economy can be much greater in a PHEV or Hybrid than in a conventional vehicle. Look at the consumer aspect of perceived vs. actual fuel economy. DOE may be working on a test of this.

5. Control strategies for meeting required emissions levels is an extremely important area of research for the OEMs.
6. Benchmarking existing battery systems/cells is important, but not developing new systems.
7. There is a need to skilled engineering graduated in key areas of hybrid systems/ components (e.g. Power electronics, motors, and motor controls)

Appendix C: Stakeholder Workshop Summary

April 29th, 2008

In Attendance

Approximately 45 people.

Represented stakeholders: EPRI, LADWP, ARB, PG&E, UC Berkeley, Mercedes-Benz, Booz Allen Hamilton, Ford, Nissan, CalCars, CEC, AAA, CalETC, SDG&E, SMUD, Friends of the Earth, Google, Public Policy Advocates LLC., DOE, SCE, VW, CALSTART, NRDC, California Senator Kehoe's staff

Questions Posed to the Stakeholders

1. Have we missed something in these 6 research tracks? Is there a major research area missing?
2. Are the timeframes reasonable? Based on regulatory timeframes.

   Near: Now - 2012

   Mid: 2012 - 2017

   Long: 20172012 - On

Responses to Initial Two Questions:

1. Research Tracks
   a. Environmental and lifetime costs, suggest it is just called "Costs" and look at all aspects of costs. Value propositions, disruptive/creative financing (first cost vs. lifecycle cost issue), total cost of ownership.
   b. Renewable energy is not on the list, or impacts of projected cost of gasoline.
   c. Expand infrastructure to include renewables and beef up that section.
   d. Add a heavy-duty section. Do we need a separate heavy-duty research track, or is it an element of each of the six main research tracks?
   e. Heavy-duty is not excluded, but is it a priority?
   f. Heavy-duty applications have greater impacts per vehicle. There are lots of regulations on medium- and heavy-duty vehicle fleets that may encourage faster adoption of the technology than passenger vehicles.
2. Timelines
   g. If batteries are available today, PHEVs would be available in 5 years.

General Research and Roadmap Suggestions

1. Make new medium and heavy duty track, maybe a section of every track devoted to medium-duty and heavy-duty vehicles.

2. Explain the efforts by Nissan, Volvo, Saab, VW, BYD, Cleannova, Eaton, International and others.
3. Do Take 1B on proposed but unfunded research by stakeholders.
4. How will this Roadmap impact the new UC Climate Center ($600 m in funds)
5. Include efforts at New York State Energy Research and Development Authority, Austin, Minnesota, HydroQuebec, Électricité de France, Japan, Washington State, UC Berkeley, UC Irvine, UC Riverside, and University of Texas.
6. Much more work needs to be collaborative, especially Advanced Metering Services research, business cases.
7. Need broad focus on how California can capture USDOE funds and also capture California jobs and industry.
8. Need to detail new federal law EISA 2007 section 641 and 131.
9. Lots of great ideas are hidden in the Research Roadmap's Appendix that needs to be brought forward to the main part of the Research Roadmap.
10. Regarding noise-emissions from quiet vehicle technologies for the visually impaired: Just mandate an audible sound above X decibels and below Y decibels. Let consumers choose vehicle sounds just like they choose ringtones, you could have deep rumbling diesel sounds, or the Jetsons' noise emanating from the bottom of the vehicle.
11. Regarding charging codes and standards: Title 24. Incentive for installing 40A/240V dedicated line in garage. National Electric Code (NEC) core for building standards. Should we in California go forward with stronger regulations, not just requiring conduit in garage, but actually requiring the wiring in the garage? Standards and certification people just looked at vehicle issues considered home/work charging requirements as part of infrastructure.
12. Are we shifting geopolitically from the Middle East as our fuel source to Africa as the source of battery materials?
13. Battery pack transportation – there are regulatory issue restricting transportation of batteries in and around the US
    a. A defective battery cannot be transported at all
    b. Testing of batteries is occurring primarily on a cell level due to size limitations
    c. How is the power tool industry resolving battery shipping/movement issues?
    d. How can automotive supplier/manufacturers cooperate with Depth of Discharge battery safety testing? Differentiation between personal electronics batteries (no shipping issues) and vehicle batteries (shipping issues).
14. The definition of stakeholder is too narrow.
15. Battery manufacturing capability in the US – Battery readiness for large scale production
16. Broader marker (not just early market) $/gal or % of budget that automakers can use

17. How to deal with consumer perception of power availability when the battery in a PHEV is fully depleted.

Vehicle Architecture Research/Timeline

Moderator: Dahlia Garas

General Suggestions

1. Need consistent and accurate units of measurement for PHEVs (not MPG) such as gr CO_2/mi and energy/mi (group decided this was more of a standards and certification issue)
2. Evaluate aftermarket companies pre-heating catalytic converter solutions. We decided as a group to leave out "evaluate conversion PHEVs" and aftermarket solutions because these are not long-term solutions. The goal is to have OEM production vehicles.

Timeline Changes

1. Evaluate pre-heating catalytic converters (E-cats) for cleaner on-off PHEV operation (2008).
2. Perform control strategy testing for emissions optimization (this may be on-going at ANL?).
3. Several suggestions along the lines of vehicle cost and architecture design optimization (2008 - ongoing).
    a. How best to take advantage of power-assist HEV commercialization (existing designs, motors, etc.)
    b. Optimal PHEV architecture for reduced fuel use and CO_2 emissions.
    c. Vehicle architecture comparisons: one motor systems vs. two motor continuously variable transmission systems.
    d. Making discrete AER available in a given PHEV platform to better optimize cost to petroleum displacement ratio. (Look at discrete increments of AER and impacts) How would such a system impact vehicle components?
    e. What is the optimal size of a battery in a PHEV and at what point does it make sense to move to and EV or simply a hybrid?
4. Evaluate need for or benefit of on-board AC kWh monitor (2009).
5. Develop total energy use vehicle instrumentation (testing for this is on consumer timeline) (2009).
6. Research auto docking starting with existing patents. (Automatically retracting extension cords. What equipment on board makes vehicle appeal to consumers?) (2012)
7. Evaluate alternative engines including fuel cells for PHEV Auxilary Power Unit (including Solid Oxide Fuel Cells) (2012)
8. Cost impact of V2H/V2G capable architectures (2015).

Consumer Behavior

Moderator: Ken Kurani

Step 1: Number the Existing Items on the Consumer Behavior Timeline

The numbering system does not itself convey any sense of priority. In the final step of this write-up, these numbers will be re-mapped onto a new timeline.

1. Consumer PHEV study launch
2. Define current consumer knowledge of HEV/PHEVs
3. Identify potential markets
4. Stud willingness to pay for PHEV technology
    a. Identify optimal consumer incentives
    b. Study consumer interest in V2H
    c. Encourage mobile electricity markets
5. Understand recharging behavior
6. Study customer response to TOU rates
    a. Test driver response to advanced PHEV energy instrumentations
    b. Develop PHEV CO_2 feedback website
7. Study consumer interest in V2G

Step 2: Elaborations of Numbered Items Above

The above list is repeated, with the added items from the workshop and breakout discussion shown in *italics*.

1. Consumer PHEV study launch (no further elaborations.)
2. Define current consumer knowledge of HEV/PHEVs
    a. *Determine what the most popular features of the hybrid are to carry over to the PHEV.*
3. Identify PHEV potential markets
    a. *How big is the PHEV market, as a function of:*
        i. *Gasoline prices*
        ii. *All-electric range (battery size)*
        iii. *EV driving capability (EV motor and battery power)*
    b. *Benchmark and update HEV market research study (This was one of Dean Taylor's submissions; however he was not in the discussion group to clarify these suggestions.)*
    c. *Study of possible geographic market segmentation of PHEVs based on regional differences in daily travel distances*
    d. *Study potential fleet markets*
    e. *Studies of pioneer PHEV drivers and manufacturers*

        i. *Interview consumer and fleet buyers of aftermarket PHEV conversions for their purchase motivations*
        ii. *Study the marketing and sales efforts of early PHEV makers, e.g, Fiskar, Aptera, etc.*
        iii. *Evaluate the effects of PHEV driver orientations, tip sheets, etc. Interview PHEV users on their expectations and the effects of learning from such programs.*
    f. *More generally, develop ways to gain qualitative and quantitative information from growing communities of PHEV drivers.*
    g. *Evaluation of education on advanced technology and customer acceptance*
    h. *Research mobile electricity markets, e.g., tailgate parties, camping, vendors, etc. Also, pre-heating and pre-cooling.*

4. Study willingness to pay for PHEV technology
    a. *Interview consumer and fleet purchasers of aftermarket conversion for purchase motivations*
    b. *Explore existence of "pivot points" at which markets become viable, e.g., gasoline price per gallon, vehicle price as a percent of household budget.*
        i. *Can such information assist manufacturer product development?*
5. (a) Identify optimal consumer incentives; (b) Study consumer interest in V2H; (c) Encourage mobile electricity markets
    a. *Analyze incentives for PHEV purchase, e.g., HOV lane access, …*
    b. *What incentives maximize consumer recharging off-peak?*
    c. *How does home (or business) solar electricity change the PHEV value proposition?*
    d. *How do renewables more generally change the PHEV value proposition?*
6. Understand recharging behavior
    a. *Is recharging a disincentive to PHEV purchase and use?*
    b. *Research the effects/desirability of easy access to plug at home, work, etc.*
7. Study customer response to TOU rates
8. (a) Test driver response to advanced PHEV energy instrumentations; (b) Develop PHEV CO_2 feedback website
    a. *Research the possibility to establish a "library" system for people to check out data logging equipment and gain access to software to demonstrate how different PHEVs configurations could fit in their lives.*
    b. *Monitor and compare multiple user interfaces and data feedback designs*
9. Study consumer interest in V2G.

Ideas Not Classified or Placed on Timeline.

Some ideas were either too general or not explained to the group by their proposer. These were not placed on the new proposed time line.

- Research on best control strategies: optimize for no more than two battery packs per vehicle lifetime, or minimize CO_2 and petroleum use, or maximize AER, or supply V2G, G2V, V2H, or mobile applications.
- Research what is a model garage—what do autos and consumers want.
- Pay as you go insurance effects on consumers.
- Consumer acceptance of power variability as a function of battery state of charge.

New Timeline

The group agreed that few of the proposed studies should be conducted only once, as the answers to questions like market potential are likely to change as conditions change, and sometimes in response to prior research. There was a general sense of compressing the original timeline, and explicitly recognizing that most proposed studies could and should be repeated over time. See the chart for the group's sense of these changed time priorities.

Batteries

Moderator: Dr. Andy Burke

1. Lifecycle analysis of batteries, cradle-to-grave, including manufacture and disposal.
   a. GHGs, Energy, Toxics, Costs
2. Calendar life vs. Cycle life (Tradeoffs)
3. Role of BEVs?
   a. Synergies of costs
   b. PHEVs leading to BEVs?
4. More Li-ion battery variations – "spectrum of technology"
   a. Maybe not for PHEV Center? – USABC job?
   b. We could focus on pre-commercial, prototypes
   c. Bench testing: cells, modules and packs
   d. Using OEM methods for "verification", performance life cycle
5. Secondary Use
   a. Multiple uses: stationary backup
   b. Very important for OEMs to setup market
   c. New applications
6. Location of Manufacturer
   a. All from China

b. Check out Enerdel (Indianapolis)
c. Get into US – policy recommendations? Societal impacts?
d. If automated, why produce foreign? Lack of pollution regulation?
e. Study possibilities of domestic production and what is needed to promote it

7. Detailed Battery Cost Studies: function and volume
    a. St each stage of volume: affordable to competitive (mass market)
8. Safety: need to experience failure, safe failure
    a. Already addressed in current testing
    b. Evaluate safety regulations? Or will this research happen anyway?
    c. Monitor what is going on? – not necessarily do research on it
9. Availability (Cost) of Materials: Li-ion
    a. Monitor availability/cost of raw materials
    b. Include recycling effects
    c. Evaluate state of Li-ion recycling
10. Evaluate Advanced Alternatives for NiMH?
    a. Likely not necessary due to Li-ion
11. Packaging of cells: safety issues
12. Evaluate opportunities for recycling
13. Also, research alternative first use of batteries, to get manufacturing costs down.

Infrastructure Research Needs

Moderator: Philip Misemer

1. Near term: Research consumer needs for opportunity charging
    a. Urban situations (apartments) with no garage/street parking
2. Near term: Research to determine charging infrastructure needs for future PHEV populations
    a. 120 vs. 240 volts
    b. V2G and V2H effects
    c. "Pay as you go"
    d. NEC
    e. Codes and Standards
3. Midterm minus: Research to determine benefits of system utilization impacts of off-peak PHEV charging
    a. Inform rate case

4. Midterm plus: Research to determine the system topology of V2G, V2H, G2V, and renewable integration.
5. Midterm plus: Research to analyze second use battery "economic" scenarios
    a. Recyclability
    b. Shelf life
    c. Battery ownership alternatives
6. Long term minus: Research to quantify benefits of PHEVs/ EVs as distributed energy source for natural disaster and security preparedness
7. Long term: Research to determine logistics of implementing smart charging
    a. SAE group is working on similar issue (Toyota, Nissan, BMW, Tesla)
8. Long term: Research to determine the adverse impact of a large number of batteries charging in "one" location (zone)
    a. Safety issue of concentration of batteries in one location (fire, flood, earthquake)

Codes and Standards Research Needs

Moderator: Kevin Nesbitt

1. On "Comet" timeline, move "Develop SAE PHEV emission standards testing to 2008 (SAE 1772, SAE 2836)
2. On "Comet" timeline, add words "Safety Evaluation" to "develop plug standards and codes."
3. On "Comet" timeline move "develop V2G communication standards to later in timeline
4. On "Comet" timeline move "develop V2H communication standards to early in timeline and raise priority
5. Develop PHEV Fuel economy sticker, "Energy Star Rating" and other easy, consumer friendly information
6. Need to research ways to mitigate hazards of "quiet" cars to seeing impaired
7. Need to establish "utility" weighting factor specific to California.

Environmental Benefits and Lifetime Costs Analysis

Moderator: Mike Nicholas

General Suggestions

1. Work to reduce cost of manufacturing, especially mass producing batteries, better automation etc.
2. Study impacts of PHEVs on economy "wealth leaving the state."
3. What is the right mix of battery sizes to affect the greatest overall $/ CO_2 benefit?

4. Given rising energy costs and carbon emissions, is there a near-term role for neighborhood PHEVs? In the long term, is there a near-term role for neighborhood EV road network connectivity to make neighborhood PHEVs viable in the future?
5. Make new costs and business case track #7
    a. Upfront cost
    b. Operating cost
    c. How to reduce cost
    d. Valve proposition issues
    e. Creative financing and disruptive businesses
6. Should we research PHEVs that combine electric drive with human-power (solar home)? How does this compare with other PHEV options?
7. Technology pathways: where does the PHEV lead us? Stay PHEV, lead to EVs, lead to plug-in fuel cell vehicles?
8. Evaluate road tax vs. utility user tax issues.

Timeline Changes

1. Cross off first three items on research timeline:
    a. Input PHEVs into current models.
    b. Input consumer use patterns.
    c. Input new info on battery second life and recyclability.
2. Replace with the following research questions:
    a. 2008 – What is $C0_2$ and materials impact of PHEVs based on consumers useable and various architectures (including power train and battery size)?
    b. 2010 – What is the impact of second life and recyclability of batteries (on labor, toxicity, energy inputs, sources, energy security, and green jobs)?
    c. 2011 – How to measure and award carbon credits? How to do so in a way to encourage certain driving/use behaviors?
3. Change fourth item on timeline "Input V2H or V2G scenarios" with "Study impact of V2H or V2G".
4. Fifth item on timeline should be an ongoing effort to continually add and update "modern" fuel properties to the models.
5. Sixth item on timeline "How to measure and award carbon credits should move to 2010-2011 timeframe.