SENTECH, *Inc.*
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Plug-In Hybrid Electric Vehicle Value Proposition Study

Interim Report:

Phase 1 Scenario Evaluation

January 2009

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SENTECH, INC

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ACRONYMS AND ABBREVIATIONS

AEO2008	*Annual Energy Outlook 2008*
AER	*all-electric range*
ANL	*Argonne National Laboratory*
CAFE	*Corporate Average Fuel Economy*
CAISO	*California Independent System Operator*
CEC 2006	*California Energy Commission End-Use Survey*
CO_2	*carbon dioxide*
CSI	*California Solar Initiative*
DOD	*depth of discharge*
DOE	*U.S. Department of Energy*
E30	*30% ethanol blend gasoline*
EIA	*Energy Information Administration*
EPRI	*Electric Power Research Institute*
GE	*General Electric Company*
GHG	*greenhouse gas*
GPRA	*Government Performance and Results Act of 1993*
GPS	*global positioning system*
GREET	*Greenhouse gas, Regulated Emissions, and Energy use in Transportation model*
HEV	*hybrid electric vehicle*
HOV	*high-occupancy vehicle*
HWFET	*highway fuel economy test*
ICE	*internal combustion engine*
IID	*Imperial Irrigation District*
kg	*kilogram*
kW	*kilowatt*
kWh	*kilowatt-hours*
LADWP	*Los Angeles Department of Water and Power*
LDC	*load duration curve*
Li-ion	*lithium-ion*
MAPS	*Multi-Area Production Simulation*
MBM	*macro business model*
MC	*managed charging*
mpg	*miles per gallon*
MSRP	*manufacturer's suggested retail price*
MW	*megawatt*
MWh	*megawatt-hours*
NC	*night charging*
NEMS	*National Energy Modeling System*
NREL	*National Renewable Energy Laboratory*
OC	*opportunistic charging*
ORCED	*Oak Ridge Competitive Electricity Dispatch model*
ORNL	*Oak Ridge National Laboratory*
OSU-CAR	*Ohio State University Center for Automotive Research*
PE&EM	*power electronics and electric machinery*
PG&E	*Pacific Gas and Electric Company*
PHEV	*plug-in hybrid electric vehicle*
PNNL	*Pacific Northwest National Laboratory*
PSAT	*Powertrain Systems Analysis Toolkit*

Pt	*platinum*
R&D	*research and development*
RESS	*rechargeable energy storage system*
RPS	*renewable portfolio standard*
SCE	*Southern California Edison*
SDG&E	*San Diego Gas and Electric Company*
SMUD	*Sacramento Municipal Utility District*
SNL	*Sandia National Laboratory*
SOC	*state of charge*
SULEV	*super ultra low emission vehicle*
T&D	*transmission and distribution*
TWh	*terawatt-hour*
UDDS	*urban dynamometer driving schedule*
URG	*utility retained generating*
US06	*light duty drive cycle for high speed, high load*
V	*volt*
V2B	*vehicle-to-building*
V2G	*vehicle-to-grid*
yr	*year*

PHEV VALUE PROPOSITION STUDY FACT SHEET

Background

Plug-in hybrid electric vehicles (PHEVs) offer significant improvements in fuel economy, convenient low-cost recharging capabilities, potential environmental benefits, and decreased reliance on imported petroleum. However, the cost associated with new components (e.g., advanced batteries) to be introduced in these vehicles will likely result in a price premium to the consumer. This study aims to overcome this market barrier by identifying and evaluating value propositions that will increase the qualitative value and/or decrease the overall cost of ownership relative to the competing conventional vehicles and hybrid electric vehicles (HEVs) of 2030.

Project Team
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Sentech, Inc.
General Electric Company
Electric Power Research Institute
Ohio State University – Center for Automotive Research

Client
U.S. Department of Energy - Vehicle Technologies Program and Office of Electricity Delivery and Energy Reliability

Duration
Sept 2007 – Dec 2009

For More Information
www.sentech.org/phev

Key Takeaways of Study

The initial case study, located in southern California, concludes that the combined operating cost savings and societal benefits attainable with PHEVs will support a commercially viable and sustainable PHEV market by 2030.

Specifically, PHEVs owners in the studied region benefit from:

- Fuel costs* reduced by 55% and 33% compared to conventional vehicles and HEVs, respectively.
- 16% less total ownership cost than conventional vehicles; 4% less than HEVs.
- Unique attributes (e.g., emergency backup power, mobile power, battery recycling credit).

The PHEV fleet of 2030 analyzed in this case study would enhance energy security and reduce environmental impacts by:

- Decreasing gasoline consumption by 80% and 70% compared to conventional vehicles and HEVs, respectively.
- Emitting 25% less carbon dioxide and total greenhouse gas emissions than conventional vehicles.
- Consuming 40% and 10% less total energy than conventional vehicles and HEVs, respectively.
- Potentially increasing utilization of domestic renewable resources.

Future Plans

Alternative geographic settings outside southern California will be studied to account for the nation's diverse range of generation mixes, climates and other variables. A second case study is currently planned for a region with a high coal-fired generation mix, such as the Tennessee Valley. Additional value may also be derived from studying regions with either highly diversified or nuclear-rich generation mixes.

A Market Introduction Study is also underway to identify action items that are critical to creating and sustaining a market for PHEVs once they are available for purchase. The project team will investigate what policies, incentives, and regulations are likely to be key enablers to accelerate commercialization of PHEVs. Critical pinch points capable of limiting the success of the PHEV market will also be identified.

** Case study assumes 30% of transportation fuel consists of ethanol; therefore, an average E30 blend was used for modeling purposes.*

EXECUTIVE SUMMARY

Overview

Sentech, Inc., Oak Ridge National Laboratory, General Electric Global Research, Electric Power Research Institute, and the Center for Automotive Research at Ohio State University have completed Phase 1 of an in-depth study that investigates the benefits, barriers, opportunities, and challenges of grid-connected plug-in hybrid electric vehicles (PHEVs) in order to establish potential value propositions that will lead to a commercially viable market by 2030. During this initial phase of this study, business scenarios were developed based on economic advantages that either increase the consumer value or reduce the consumer cost of PHEVs to assure a sustainable market that can thrive without the aid of state and Federal incentives or subsidies. Once the characteristics of a thriving PHEV market have been defined for this timeframe, market introduction steps, such as supportive policies, regulations and temporary incentives, needed to reach this level of sustainability will be determined.

PHEVs have gained interest over the past decade for several reasons, including their high fuel economy, convenient low-cost recharging capabilities, potential environmental benefits and reduced use of imported petroleum, potentially contributing to President Bush's goal of a 20% reduction in gasoline use in ten years, or "Twenty in Ten." PHEVs and energy storage from advanced batteries have also been suggested as enabling technologies to improve the reliability and efficiency of the electric power grid. However, PHEVs will likely cost significantly more to purchase than conventional or other hybrid electric vehicles (HEVs), in large part because of the cost of batteries. Despite the potential long-term savings to consumers and value to stakeholders, the initial cost of PHEVs presents a major market barrier to their widespread commercialization. The purpose of this project is to identify and evaluate value-added propositions for PHEVs that will help overcome this market barrier.

In 2030, PHEVs will be competitive with other vehicles, offering:

- *Reduced fuel costs* at only 6¢/mile (compared to HEVs at 9¢/mile and conventional vehicles at 13.5¢/mile)*
- *16.5% less total ownership cost than conventional vehicles; 4% less than HEVs*
- *Unique attributes (e.g., emergency backup power, mobile power, battery recycling credit)*

** E30 (and electricity if applicable)*

Candidate value propositions for the initial case study were chosen to enhance consumer acceptance of PHEVs and/or compatibility with the grid. Potential benefits of such grid-connected vehicles include the ability to supply peak load or emergency power requirements of the grid, enabling utilities to size their generation capacity and contingency resources at levels below peak. Different models for vehicle/battery ownership, leasing, financing and operation, as well as the grid, communications, and vehicle infrastructure needed to support the proposed value-added functions were explored during Phase 1. Rigorous power system, vehicle, financial and emissions modeling were utilized to help identify the most promising value propositions and market niches to focus PHEV deployment initiatives.

A Guidance & Evaluation Committee composed of representatives from various stakeholder organizations contributed expertise throughout Phase 1 of the study. Committee members include executives and entrepreneurs from the automotive, energy storage, utility, and finance arenas. In addition, participation by several national laboratories, including Pacific Northwest National Laboratory, National Renewable Energy Laboratory, and Argonne National Laboratories, were sought.

Approach

Over 120 representatives from the automotive, battery, utility, and supplier industries attended the PHEV Value Proposition Workshop held at the L'Enfant Plaza Hotel in Washington, D.C. on December 11-12, 2007. The objective of the workshop was to bring together experts from a full range of stakeholders to brainstorm potential business models that would lead to a commercially viable PHEV market and supporting infrastructure. The outcome of this workshop was an extensive list of potential value propositions, assumptions, and a consensus vision of 2030. Forecasts included anticipated regulatory changes, technology breakthroughs, infrastructure characteristics, nature of fuel supply, and more. Key assumptions included in the PHEV Value Proposition Study:

PHEVs enhance energy security and reduce environmental impact by:

- *Reducing gasoline consumption by 70% and 80% compared to HEVs and conventional vehicles, respectively.*
- *Emitting 1/4 less CO_2 and total GHG emissions than conventional vehicles.*
- *Consuming 10% and 40% less total energy than HEVs and conventional vehicles, respectively.*
- *Potentially increasing utilization of domestic renewable resources.*

- A 10% market penetration rate in 2030 to observe maximum effects on the grid.
- A tax associated with carbon emissions at $30 per ton of carbon dioxide (CO_2) in current dollars.
- First generation PHEV chargers may only be capable of charging at 110V. However, dual voltage chargers will become the dominant charging type by 2030, accommodating quick charging, vehicle-to-building (V2B) and eventually vehicle-to-grid (V2G) applications.
- Battery recycling capabilities will be in place due to regulations.
- The U.S. Department of Energy cost targets through 2030 will be met for all powertrain components (e.g., battery, power electronics).
- 30% of transportation fuel will be cellulosic ethanol; for modeling purposes, this was approximated by using an E30 average blend. The same vehicles were also analyzed using an E10 average blend.
- Vehicles are anticipated to have a ten year lifetime (~150,000 miles).
- PHEVs analyzed in this study will have an all-electric range (AER) equivalent of 30 miles in 2030 although a variety of electric ranges will exist for PHEVs.

The primary challenge facing the PHEV industry is the ability to create vehicles with batteries reliable enough to simply turn the wheels, the basis for reduced operating costs to the owner. More advanced concepts, such as ancillary services and load response, V2G operations or third party ownership of batteries, are secondary to this basic “battery turning the wheels” concept, and they also require much preliminary modeling data (e.g., vehicle performance, electricity costs, electric system operations, and market size) that must be obtained by first studying the “battery turning the wheels” concept. Therefore, the project team decided to model a PHEV “baseline” fleet of 2030 for Phase 1 of this study in order to direct focus on the primary goal of demonstrating lower operating costs for the driver. In future phases, this scenario will be enhanced to accommodate more advanced value propositions whose parameters are dependent on the power system and vehicle operating characteristics gathered in Phase 1.

The project team chose southern California as the Phase 1 case study location. Reasons for this location selection include the state’s carbon policy, large number of early adopters of internal combustion engine hybrids, high sales of hybrid vehicles, aggressive renewable portfolio standard (RPS) targets, and emission-constrained dispatch of power plants in the Los Angeles air basin. These economic, environmental, social and regulatory conditions are conducive to the advantages of PHEVs.

Assuming market incentives that support steady growth of PHEV sales over the next two decades and additional interest of early adopters, PHEVs in this area are postulated to comprise about 1 million of the area’s private vehicles in 2030. The PHEV-30 model used in this study contains a 14 kWh Li-ion battery with approximately 8 kWh of usable operating range.[a] The additional 6 kWh was designed to provide safety margins from battery overcharge / overwork and to account for anticipated AER degradation over ten years. PHEV batteries may be classified by either a blended mileage description (e.g., 100 mpg, 150 mpg), an ownership cost (sum of costs per mile for fuel and electricity), or combination of the two that demonstrates a battery size equivalence of a PHEV-30.

The characteristics of the southern California utilities’ current power systems and California Independent System Operator provided the initial data for modeling the 2030 power system. The load forecasts, fuel price forecasts, and generation expansion plans for southern California were used to estimate the characteristics of the 2030 power system. However, the forecasted generation mix for 2030 was modified to incorporate a 30% RPS and expected improvements to power generation technologies, such as increased efficiencies and reduced emissions. In addition, input for price values and sensitivity ranges used the Energy Information Agency (EIA) Annual Energy Outlook 2008 and Workshop projections, shown on the following page.

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[a] Usable operating range could fall between 6-9 kWh depending on battery model configuration and vehicle size. The 8 kWh for a mid-size sedan was determined using the project team’s modified PSAT model.

	EIA Projections	Workshop Predictions	Sensitivity Range
Carbon "Tax" (2006 $ / ton of CO_2)	-	30	0 – 50
Fuel Price (2006 cents / gal)	244.6	450	200 – 800
Electricity Rate[b] (2006 cents / kWh)	13.4	-	5 – 25 [c]
Ethanol Content	-	30	10 - 30%
All-Electric Range (mi)	-	-	15 - 30
Vehicle Weight Reduction	-	-	0 – 30%

Phase 1 Case Study Results

To reach commercial viability, the reduced operating costs attainable with PHEVs must match or outweigh their initial price premium over conventional vehicles or HEVs. Based on the results from the Phase 1 case study set in southern California, the reduced operating costs of PHEVs accrued over its ten year lifetime (~15,000 vehicle miles traveled annually) do indeed result in significant net cost savings over both conventional vehicles and HEVs.

MONETARY VALUE	CONVENTIONAL	HEV	PHEV-30
PURCHASE COSTS	**$21,400**	**$22,600**	**$26,675**
Glider [d]	**$14,400**	**$14,400**	**$14,400**
Powertrain Costs	**$7,000**	**$8,200**	**$12,275**
Engine[e]	$4,250	$2,500	$2,500
Transmission[f]	$2,750	$2,625	$2,625
Motor/Inverter [f]	-	$875	$875
Battery [f]	-	$2,200	$5,600
Charging Plug[e]	-	-	$675
OPERATING COSTS	**$28,325**	**$20,450**	**$15,725**
E30	**$20,625**	**$13,775**	**$4,250**
Electricity	**-**	**-**	**$5,350**
Maintenance	**$6,600**	**$5,925**	**$5,275**
Carbon Tax	**$1,100**	**$750**	**$850**
OWNERSHIP $ BENEFITS	**-**	**-**	**($1,000)**
Battery Recycle Credit	**-**	**-**	**($1,000)**
TOTAL NET COST	**$49,725**	**$43,050**	**$41,400**

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[b] End-Use Prices – Residential (California). No carbon tax included.

[c] Range includes a mixture of off-peak and on-peak rates

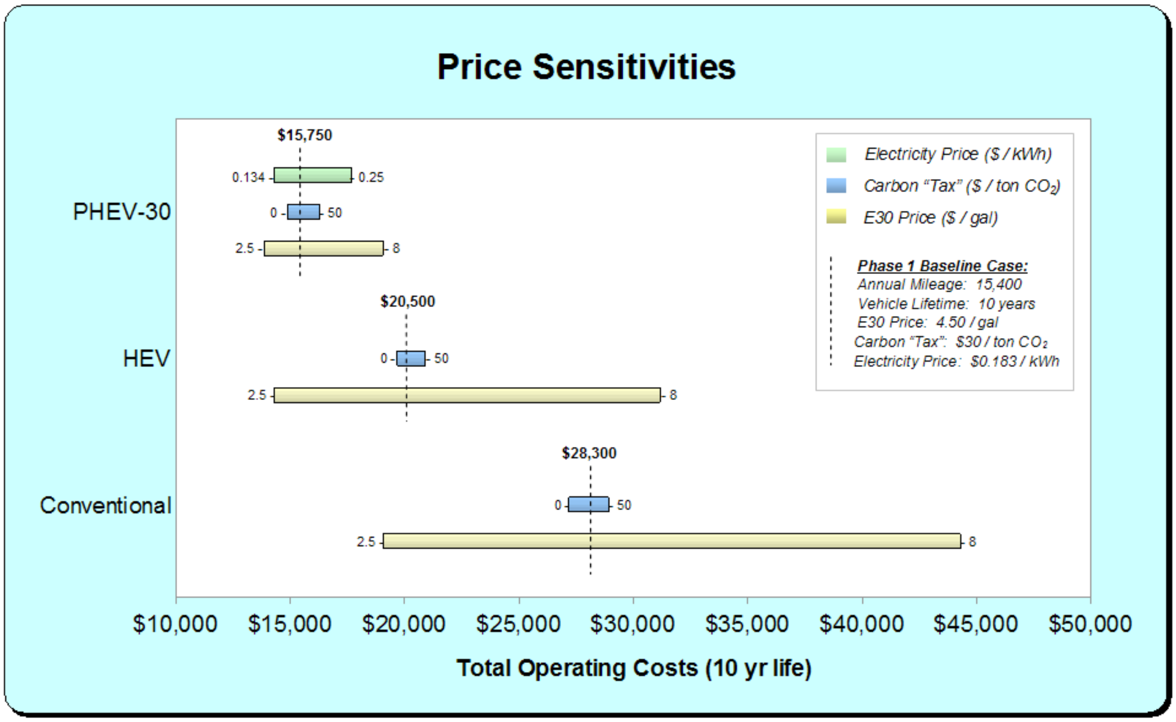
[d] MSRP of 2009 Toyota Camry SE Base Model (2.4L 4-Cyl.) minus total powertrain costs.

[e] Graham, R. et al. "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options." Electric Power Research Institute. Report Number 1000349. July 2001.

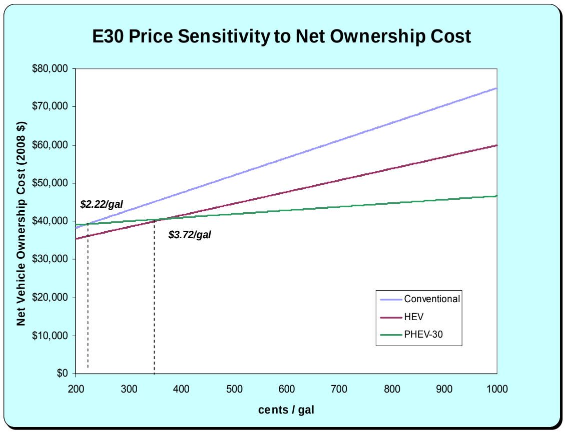
[f] FCVT Multi-Year Program Plan. U.S. Department of Energy. April 20, 2008.

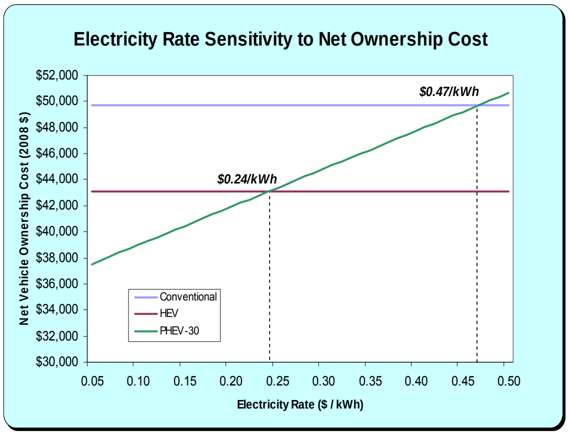
Case study results show that liquid fuel and electricity costs for a PHEV-30 are projected to be approximately 6¢ per mile. This compares to a projected conventional vehicle fuel cost of more than twice that, about 13.5¢ per mile and a projected HEV fuel cost of about 1.5 times that, about 9¢ per mile. Over the lifetime of the vehicle, this reduced cost per mile more than outweighs the anticipated ~$5,300 price premium relative to the conventional vehicle. An anticipated recycling credit of approximately $1,000 for an "end-of-life" Li-ion battery pack also increases the PHEV's competitive edge. Furthermore, these savings are prior to additional value-added propositions, such as benefits to auto manufacturers, utilities or government agencies.

The price sensitivity chart in Figure 20 demonstrates the impact of varying retail prices of E30 and electricity used to power the three vehicle types, assuming all other factors held constant. PHEVs appear to have the lowest overall cost volatility primarily because the effects of price changes can be shared between two fuel types, which is not an option for conventional vehicles or HEVs. Variations in carbon tax rates are also displayed in this chart; all vehicle types are similarly affected by fluctuations in the rate, which result in small changes in operating cost.



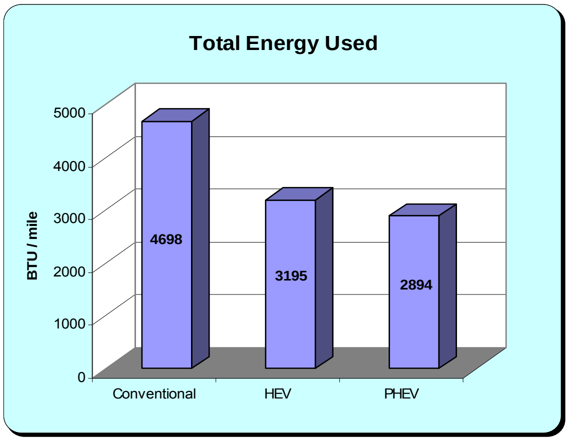
More specifically, the next figures shows the estimated retail price thresholds for E30 and electricity rates at which PHEVs become the most economic choice with respect to total vehicle ownership cost. With all other parameters held constant, PHEVs are the most economic choice compared to conventional vehicles as long as E30 prices exceed $2.22 per gallon and electricity rates are below $0.47/kWh (including transmission and distribution). HEVs, on the other hand appear to be the most financially responsible purchase unless E30 prices exceed $3.72 per gallon and electricity rates are below $0.24/kWh, in which case PHEVs become most financially appealing.

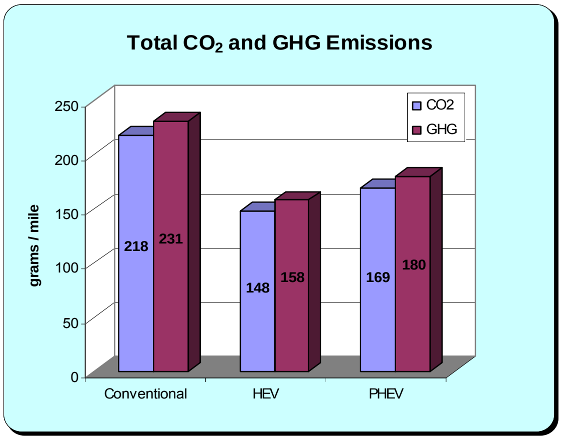




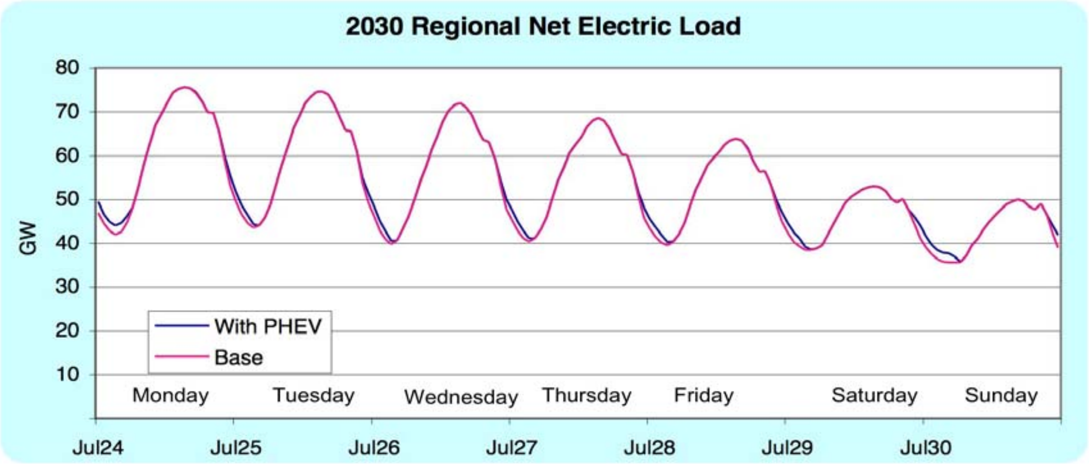
In addition to monetary benefits, PHEVs offer significant benefits to society, including reduced imported oil and decreased greenhouse (GHG) emissions. PHEVs are able to dramatically decrease dependence on foreign oil by substituting the majority of it with electricity. Case study results show that, on average, a single PHEV-30 will consume approximately 80% less gasoline than conventional vehicles (~250 less gallons annually) and 70% less gasoline than HEVs (~150 less gallons annually). With 60% of oil imported from foreign lands, the southern California fleet of 1 million PHEVs has the potential to reduce imported oil by approximately 8 million barrels (150 million gallons) annually if the PHEV fleet substituted for conventional vehicles or by approximately 4.5 million barrels (90 million gallons) annually (if the PHEV fleet substituted for HEVs).

As shown in the next figure, PHEVs also demonstrate significant improvements in GHG emissions reductions in some cases. Relative to conventional vehicles, PHEVs reduce both CO_2 emissions and overall GHG emissions by nearly one quarter primarily due to less petroleum burned. PHEVs also use approximately 40% and 10% less total energy compared to conventional vehicles and HEVs, respectively. CO_2 and GHG emissions for PHEVs and HEVs appear to balance out, depending on the ethanol blend used and the weight of the vehicle. When an E30 blend is used on a lighter weight vehicle (as shown below), PHEV emissions are slightly higher. When an E10 blend is used on a vehicle of traditional weight, however, HEVs have slightly higher emissions.



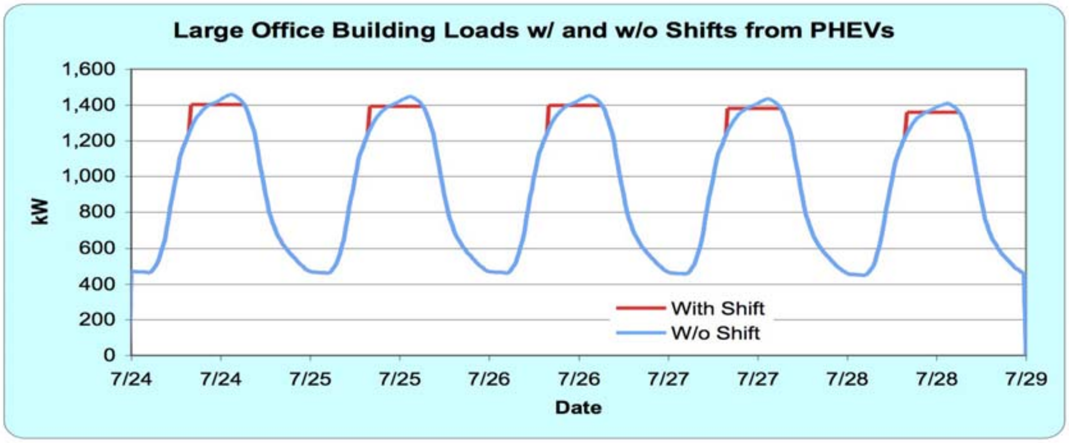


The relatively slow penetration of PHEVs in the market in combination with smart charging that shifts demands to off-peak times leads to very little impact on overall peak demands while providing the utility with additional sales during off-peak times (see figure below). The benefits to the utility include increased sales from existing generating capacity, thereby providing the potential to recover more of their fixed costs. If all PHEV owners choose to charge their vehicles in the evening (5 PM – 6 PM), however, resulting peak demands could have a negative affect on the grid. Such effects clearly show the benefit to the utility of providing incentives for customers to shift their charging times to nighttime. PHEV owners must, therefore, be educated on what hours offer the highest financial benefits and understand why charging during peak hours is discouraged by the utilities.



Commercial building owners may also benefit from allowing their employees to plug in at their workplace upon arrival in the morning. By charging the batteries when demands at the building are below peak, commercial building owners can use the power stored in the batteries towards reducing peak billing demand and thereby lowering their electric bill. At the same time, some of their electricity purchases could be shifted from afternoon peak prices to morning mid-peak prices, saving additional funds. However, the total savings is dependent on the load shape of the facility. Also, the vehicle owners will expect some form of compensation, either monetary rebates or non-monetary incentives (e.g., preferred parking spaces), for wear and tear on the battery. They will also expect to have at least the same SOC when they leave work as they did upon arrival. Also, the net savings to the building will need to be sufficient to justify the capital costs and ongoing operations cost for the program.

For a large office building with a 1.5 MW peak demand and up to fifty PHEVs available, the building's owners could purchase extra power in the morning to recharge the batteries to full charge. Then in the afternoon, the building could withdraw that power, squaring off each day's peak as shown below. In this example, PHEVs began plugging in at 8 AM, charged through the morning, and then released the same amount of energy in the afternoon. This dropped the peak demand roughly 60 kW. Using current Southern California Edison and Los Angeles Department of Water and Power commercial tariffs, the savings from both reduced demand charge and lower cost energy purchases was $1000-2000 per month. By 2030, the amount will likely increase, but the amount of savings depends on the building's rate structure.



Action Items between Now and 2030

To ensure a successful introduction of PHEVs and subsequent thriving market, several pressing issues must be addressed over the course of the next two decades:

- *Increased Federal Research and Development (R&D) for Advanced Batteries:* The cost of batteries may be the single largest impediment to large scale commercialization of PHEVs. In order to produce PHEV batteries that meet the required levels of durability, quality and safety at an affordable cost, increased Federal R&D for industry, universities, national laboratories and domestic battery manufacturers is needed.
- *Increased Domestic Battery Manufacturing Capacity:* The U.S. must establish a competitive edge and leadership role in the PHEV battery industry in order to avoid replacing imported oil with imported batteries. To ensure an ample supply of domestically produced batteries that consistently meets or exceeds the demand for PHEV batteries, expansions in domestic manufacturing capacity must take place. Therefore, incentives to make domestic production both appealing and worthwhile to battery manufacturers are necessary.
- *Passage of Supportive Policies and Regulations:* Similar to the introduction of HEVs, policies that offer financial incentives to potential PHEV owners are useful to significantly boost market penetration. Favorable PHEV policies would include tax credits to PHEV purchasers, converters and utilities. A nationwide RPS and fuel efficiency standard would also contribute to steady growth of the PHEV market.
- *Consumer Education:* To accrue the level of lifetime savings and benefits demonstrated in this study, PHEV owners must be knowledgeable of how to optimally charge their vehicle. Consumer education would be necessary to teach owners to not only fully charge each night but also charge opportunistically (when total daily commutes are expected to exceed 30 miles) to maximize electric range. Owners must also be aware of the monetary

benefits associated with charging during “off-peak” hours as opposed to during the more expensive “peak” hours.

- *Distribution System Improvements.* If concentrated segments of the population own two or more PHEVs and they use a quick-charge at 220V, it is possible that the local distribution system may not be able to support the extra load. Multiple houses served by a single transformer, or an apartment building with a limited size service and transformer, may need to be upgraded to handle the increased load. Smart chargers can alleviate this by monitoring conditions on the local lines as well as system wide power in order to optimize charging schedules of multiple vehicles.
- *Growth toward a Robust Private and Public Charging Infrastructure:* The majority of consumers do not have access to personal garages or carports for charging their vehicle. Therefore, steps should be taken to provide public charging stations in frequented areas throughout most cities, including parking garages, work locations, and shopping areas, to accommodate PHEV charging during the day. Funding for such installations capable of smart metering and time differentiated rates should be sought in preparation for the introduction of PHEVs. A payment infrastructure that enables consumers to purchase electricity at locations other than their homes and to monitor their electricity costs needs to be addressed. Also, since future PHEVs are expected to offer 220V quick charging capabilities (in addition to 110V or exclusively), potential PHEV owners should be aware that installation of a 220V outlet may be necessary. Reinforcements to overloaded distribution may also contribute to needed infrastructure growth.
- *Collaboration among Major Industry Leaders*: The synergy produced by linking vehicles to the grid creates a novel opportunity for auto manufacturers and utilities that has heretofore never been considered. Both entities have a mutual goal of designing PHEVs that exhibit optimal interaction with the grid, ultimately resulting in added value to their joint costumers.
- *Collaboration with the Education System*: While today’s car is a modern marvel of mechanical engineering, tomorrow’s car will also be a modern marvel of electrical engineering. Ideally, a sustainable high-volume PHEV market will be one that is seamlessly integrated with the grid. Accordingly, the auto industry must undertake an ambitious effort to transition toward the manufacturing, sales, and servicing of electronically-powered products, and the utilities face a similar challenge with PHEVs. While the transition from HEVs to PHEVs will provide the auto industry with a substantive learning experience, the educational system can accelerate the transition by training electrical engineers and technicians skilled in servicing batteries and electrical systems. The education system will also need to address the need for increased environmental and energy awareness of the public, who will be the customers driving the demand for PHEVs and also interacting with the grid. It is essential that consumers are educated on what vehicle is the “best buy” and how is the best way to use it.

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1. INTRODUCTION

1.1. Project Overview

Sentech, Inc., Oak Ridge National Laboratory (ORNL), General Electric (GE) Global Research, Electric Power Research Institute (EPRI), and the Center for Automotive Research at Ohio State University (OSU-CAR) have completed Phase 1 of an in-depth study that investigates the benefits, barriers, opportunities, and challenges of grid-connected plug-in hybrid electric vehicles (PHEVs) in order to establish potential value propositions that will lead to a commercially viable market. During this initial phase of the study, business scenarios were developed based on economic advantages that either increase the consumer value or reduce the consumer cost of PHEVs to assure a sustainable market that can thrive without the aid of state and Federal incentives or subsidies. Once the characteristics of a thriving PHEV market have been defined for this timeframe, market introduction steps, such as supportive policies, regulations and temporary incentives, needed to reach this level of sustainability will be determined.

The primary value of PHEVs to the consumer is their potential to markedly reduce fuel cost by substituting gasoline with electricity. Since this alone may not be enough to offset the increased purchase price of the PHEV when the consumer makes a buying decision, other potential advantages of PHEVs were identified and, to the extent possible, their values were quantified. Candidate value propositions for the initial case study were chosen to enhance consumer acceptance of PHEVs and/or compatibility with the grid. Potential benefits of such grid-connected vehicles include the ability to supply peak load or emergency power requirements of the grid, enabling utilities to size their generation capacity and contingency resources at levels below peak. Different models for vehicle/battery ownership, leasing, financing and operation, communications, and vehicle infrastructure needed to support the proposed value-added functions, were explored during Phase 1. Rigorous power system, vehicle, financial and emissions modeling were utilized to help identify the most promising value propositions and market niches to focus PHEV deployment initiatives.

A Guidance & Evaluation Committee composed of representatives from various stakeholder organizations contributed expertise throughout Phase 1 of the study. Committee members include executives and entrepreneurs from the automotive, energy storage, utility, and finance arenas. In addition, participation by several national laboratories, including Pacific Northwest National Laboratory (PNNL), National Renewable Energy Laboratory (NREL), and Argonne National Laboratories (ANL), was sought.

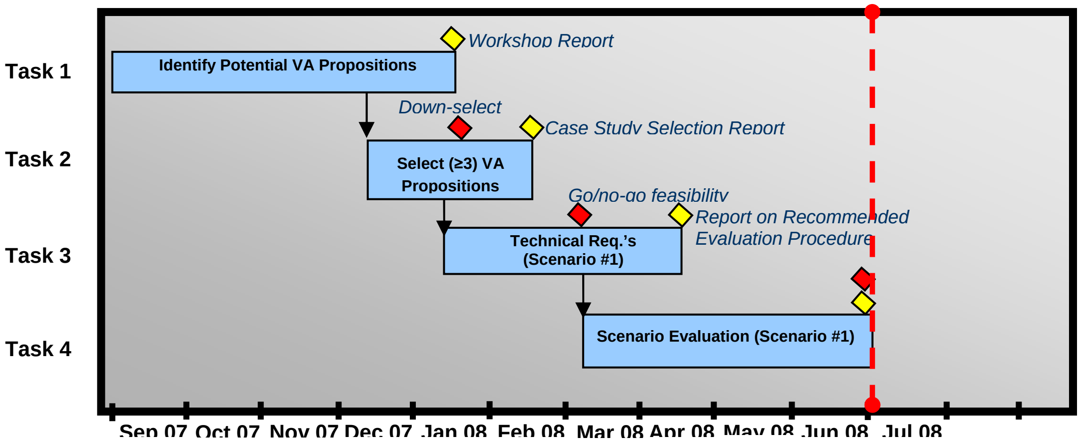
1.2. Purpose of Study

PHEVs have attracted increased interest over the past decade for several reasons, including their high fuel economy, convenient low-cost recharging capabilities, potential environmental benefits and reduced use of imported petroleum, potentially contributing to President Bush's goal of a 20% reduction in gasoline use in ten years, or "Twenty in Ten." PHEVs have also been suggested as an enabling technology to improve the reliability and efficiency of the electric power grid. However, PHEVs will likely cost significantly more to purchase than conventional or other hybrid electric vehicles (HEVs), in large part because of the cost of batteries. Despite the potential long-term savings to consumers and value to stakeholders, the initial cost of PHEVs presents a major market barrier to their widespread commercialization. The purpose of this project is to identify and evaluate value-added propositions for PHEVs that will help overcome this market barrier. The conclusions of this analysis will help ensure effective utilization of past research and development (R&D) innovations and will be used as a basis for investment decisions in the future. The U.S. Department of Energy (DOE) also expects to utilize the results of this study to develop future R&D strategies and to help formulate policy recommendations. Furthermore, the creation of a viable PHEV market will contribute to the nation’s energy security, environmental protection, and economic stimulation.

1.3. Project Status

As indicated by the vertical dashed red line in Figure 1, Phase 1 has been completed. Assuming the project team is granted a “Go” after the Phase 1 interim report, Phase 2 will commence with the identification of technical requirements and evaluation procedures needed to analyze future case studies that investigate new geographic settings, representing a wider range of generation mixes, beyond the Phase 1 scenario. Input from Phase 1 will be vital for the successful completion of future phases.

PHASE 1



PHASE 2

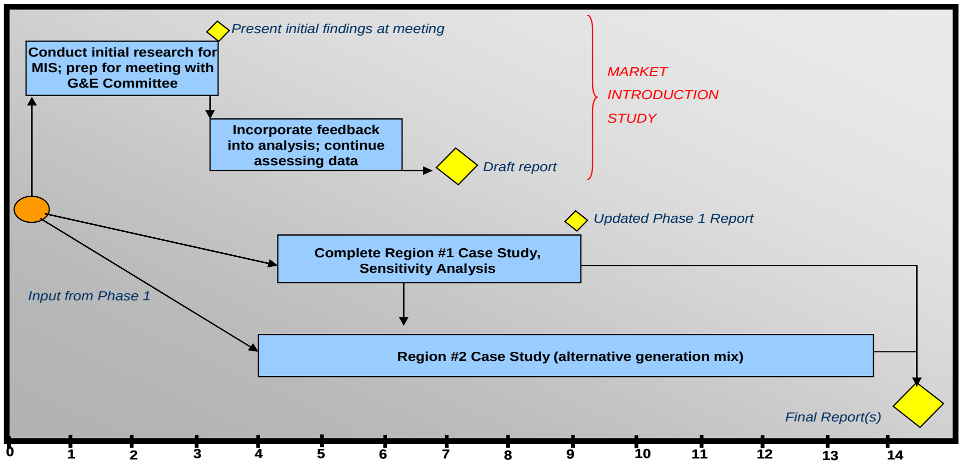


Figure 1: *Current status of the PHEV Value Proposition Study.*

2. APPROACH

2.1. PHEV Value Proposition Workshop

Over 120 representatives from the automotive, battery, utility, and supplier industries were in attendance at the PHEV Value Proposition Workshop held at the L'Enfant Plaza Hotel in Washington, D.C. on December 11-12, 2007. The objective of the workshop was to bring together experts from a full range of stakeholders to brainstorm potential business models that would lead to a commercially viable PHEV market and supporting infrastructure.

The "value propositions" developed at this workshop consisted of methods to enhance consumer acceptance of PHEVs as well as increase PHEV compatibility with the grid. Areas of interest included the operation (charge and discharge) of PHEVs, capabilities or functions of PHEVs, different methods for financing and leasing PHEVs and/or their batteries, grid infrastructure and communication needs, and types of non-monetary incentives that would be valued by PHEV owners, such as access to high-occupancy vehicle (HOV) lanes.

Participants were assigned to one of five highly interactive breakout sessions (listed below). Breakout Sessions 1 – 4 focused on a specific area for potential added value while participants in Breakout Session 5 used industry expertise to envision the world of 2030 and beyond, when the PHEV market is anticipated to reach sustainability. The five breakout sessions were titled:

1. What are the value propositions for unidirectional electric flow?
2. What are the value propositions for PHEVs with third party ownership of batteries?
3. What are the value propositions for PHEVs with vehicle-to-grid (V2G)?
4. What are the value propositions for PHEVs with vehicle-to-building (V2B)?
5. What is the consensus vision of 2030 and beyond?

In each breakout session, participants brainstormed potential value propositions related to their topic, and all suggested value propositions were documented. Participants then voted for their top value propositions, basing their decision on the level of impact that the proposition would have on the PHEV industry and the mechanisms required for implementing the proposition. Once the top propositions were identified, each group defined them in greater detail, noting characteristics such as key enablers and barriers. On the morning of the closing day, top propositions from each breakout session were summarized and presented during the final plenary session. Table 1 on the following page is a comprehensive list of 32 value propositions documented at the Workshop after consolidation.[1]

Table 1: *Complete list of value propositions generated from the PHEV Value Proposition Workshop*

VALUE PROPOSITIONS
Applicable to PHEVs with Unidirectional, V2G, or V2B Capabilities
Fuel cost savings (with GPS-enabled fuel optimization dispatch)
Reduced vehicle maintenance costs
Emissions reduction
Increased use of renewable energy in generation mix
Reduced petroleum imports
Carbon “tax” equivalent
Opportunistic charging / ability to refuel from any outlet for portion of fleet
Time dependent electricity pricing for PHEV owners
Recognition of “social” responsibility
Tailgate/camping, limited household appliance backup (residential V2B) capabilities
Utility cost savings (capital or production) in $/kWh for serving PHEVs
Responsive load – utility control of charger
Increased use of renewable energy in home
Convenient charging locations (e.g., at airports, municipalities, etc.)
Battery recycling credit
Applicable to PHEVs with V2G or V2B Capabilities Only
Reduced billing demand for commercial building (commercial V2B)
Emergency back-up power for commercial facility (commercial V2B)
Responsive load - V2B capability
Enhanced responsive load - V2G capability
Ancillary services – distribution system voltage support (V2G)
Ancillary services – bulk power system (V2G) ➢ Spinning reserves ➢ Regulation ➢ Volt/var support
Increased use of renewable energy through system regulation
Coordination of rail mass transit and PHEVs in parking lot
Additional Value Propositions Requiring Business Sub Models
Extended battery warranty
Third party ownership of battery (utility, leasing company, oil company, other)
Battery recycling, re-use credit, buy-back program
Aggregator use of parking garages
Emissions credit trading
Incentives Applicable to Market Introduction
Federal government incentives/programs/tax credits
State government incentives/programs/tax credits
HOV access, reduced tolls, city center or restricted street access
Preferred parking

2.2. Assumptions

The construction of business models requires projections spanning the next two decades. Since the world of 2030 is anticipated to undergo a variety of economic and technological transitions during this timeframe, many assumptions were set to allow realistic business scenarios to be built. To assist in defining these assumptions, the project team drew from the recommendations of Workshop participants in Breakout Session 5, who were tasked with creating a "Consensus Vision for 2030-2040." Forecasts included anticipated regulatory changes, technology breakthroughs, infrastructure characteristics, nature of fuel supply, and more occurring between now and 2030. Below is a complete list of assumptions that combines insight from Breakout Session 5 participants with further projections developed by the project team to be included in the PHEV Value Proposition Study:

- To be sustainable, a PHEV fleet must comprise 5-10% of new vehicles sold annually. Workshop participants agreed that this volume may be realistically achievable by 2030. The project team aimed for a 10% market penetration rate in 2030 to be able to observe any significant effects on the grid.
- Corporate Average Fuel Economy (CAFE) standards will be greater than 35 miles per gallon in 2030.
- Oil cost will continue to increase to over $150 per barrel by 2030. Cost of other fuels, including electricity derived from petroleum or natural gas, will also rise significantly.[g]
- A cost will be associated with carbon emissions roughly in the range of $30-50 per ton of CO_2 in current dollars. This carbon tax will be regulated on an international basis.
- PHEVs' first challenge should be to simply demonstrate the capability of reliable transportation before attempting more advanced applications, such as V2B or V2G. Participants agree V2B applications would likely be adopted by 2030, including supporting infrastructure. However, the broad implementation of V2G applications is believed to be unlikely before 2030.
- First generation PHEV chargers may only be capable of charging at 110V. However, dual voltage chargers will become the dominant charging type by 2030, accommodating quick charging, vehicle-to-building (V2B) and eventually vehicle-to-grid (V2G) applications.
- The majority of the PHEV fleet will be capable of only unidirectional electricity flow by 2030, though they will still be able to provide limited power for off-road or emergency use.
- Battery recycling capabilities will be in place due to regulations.
- Li-ion will be the dominant battery chemistry used by the PHEV fleet in 2030. All new PHEVs sold after 2030 are assumed to have Li-ion batteries. Therefore, only Li-ion batteries were analyzed in this study.
- DOE cost targets through 2030 will be met for all powertrain components (e.g., battery, power electronics).

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[g] Energy Information Administration (EIA) fuel price projections were used initially to specify the Phase 1 scenario parameters, especially to determine the relative costs of oil, natural gas, electricity, and other fuels. However, since the project team and the Guidance and Evaluation Committee believe these price projections may be too low, revised fuel price projections were also used to evaluate the value propositions. These revised price levels were to be consistent with the long-term planning assumptions made by the state and utilities chosen for the Phase 1 case study.

- PHEV batteries will be capable of 4000 cycles.
- All vehicles produced in 2030 will meet SULEV (super ultra low emission vehicle) standards.
- 30% of transportation fuel will be cellulosic ethanol; for modeling purposes, this was approximated by using an E30 average blend. For comparison purposes, the same vehicles were also analyzed using an E10 average blend.
- Fuel economy of all vehicles will benefit from a 30% weight reduction in 2030 relative to today's vehicles. For comparison purposes, the same vehicles were also analyzed with no weight reduction.
- Vehicles are anticipated to have a ten year lifetime (~150,000 miles).
- PHEVs analyzed in this study will have an all-electric range (AER) equivalent of 30 miles in 2030 although a variety of electric ranges will exist for PHEVs.
- Advanced metering and roaming will be available nationwide by 2030.
- From an accounting standpoint, PHEVs will be separately tracked and billed (i.e., a "virtual" meter) to enable "roaming" charging away from home. This is not to be confused with the traditional model of a separately installed billing meter.

2.3. Phase 1 Considerations

As identified in the Assumptions, the first and foremost challenge facing the PHEV industry is the ability to create vehicles with batteries reliable enough to simply turn the wheels, the basis for reduced operating costs to the owner. More advanced concepts, such as ancillary services and load response, V2G operations, or third party ownership of batteries, are secondary to this basic "battery turning the wheels" concept, and they also require much preliminary modeling data (e.g., vehicle performance, electricity costs, electric system operation, and market size) that must be derived by first studying the "battery turning the wheels" concept. Therefore, the project team decided to model a PHEV "baseline" fleet of 2030 for Phase 1 of this study in order to direct focus on the primary goal of demonstrating lower operating costs for the driver. In future phases, this scenario will be enhanced to accommodate more advanced value propositions whose parameters are dependent on the power system and vehicle operating characteristics gathered in Phase 1.

The project team has initiated its investigation of a third party owning and leasing batteries to PHEV customers. The simulation of third party business strategies requires the construction of complex business sub-models that include a mix of leasing, refurbishing, reusing, and selling strategies. Since the financial and technical requirements needed to build such business sub-models cannot be fully completed until the "basic" PHEV economics (e.g., PHEV driving characteristics, battery charge/discharge cycles) are determined in Phase 1 analysis, the project team will continue to pursue third party ownership business sub-models in greater detail in future case studies.

For similar reasons, the Phase 1 case study deferred evaluating V2G applications until Phase 2 case studies. The decision was based on the Guidance and Evaluation Committee's belief that the estimated market size and value of PHEV-provided ancillary services are very dependent on a region's generation mix and the power system's dispatch parameters. Such values have not been sufficiently specified for a 2030 time horizon with a sizeable PHEV load assumed. The development of a consistent set of assumptions and model parameters must be defined before the evaluation of most V2G value propositions can be realistic. Therefore, V2G value propositions will be examined in future phases using power system data, ancillary services market information, and vehicle characteristics collected in Phase 1 analyses.

Finally, several value propositions suggested by Workshop participants lack permanence due to eventual saturation (e.g., high occupancy vehicle lane access, preferred parking, government-issued incentives). Consequently, fewer and fewer consumers will be able to take advantage of these value propositions as the size of the fleet grows. Therefore, case studies will only consider these as incentives used to accelerate market introduction in the short term.

2.4. Scenario Selection

The project team chose southern California as the Phase 1 case study location. Reasons for this location selection include the state's carbon policy, large number of early adopters of internal combustion engine (ICE) hybrids, high sales of hybrid vehicles, aggressive renewable portfolio standard (RPS) targets, and emission-constrained dispatch of power plants in the Los Angeles air basin. These economic, environmental, social and regulatory conditions are conducive to the advantages of PHEVs.

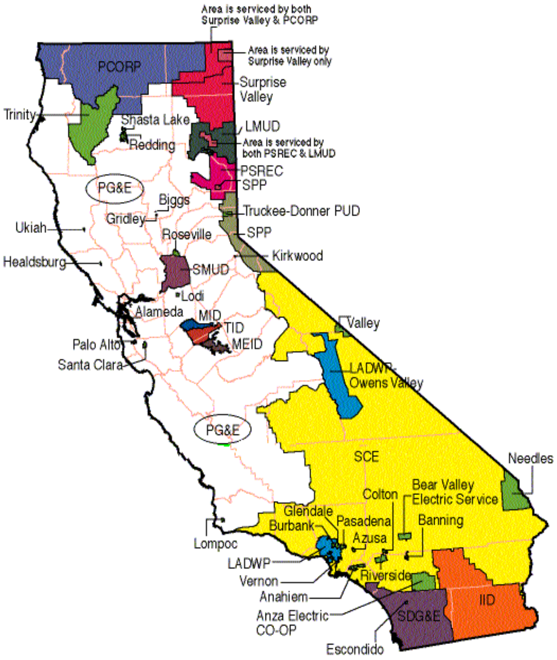

Figure 2: *California's electric utility service areas.*
Source: *Lassen Municipal Utility District (1996).*

The southern California region includes numerous utilities (Figure 2), of which the major ones are Southern California Edison Company (SCE) and Los Angeles Department of Water and Power (LADWP). They are dispatched by the California Independent System Operator (CAISO) as part of a power pool of California's utilities. In addition to SCE and LADWP, other major California utilities include Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric Company (SDG&E), Sacramento Municipal Utility District (SMUD), and Imperial Irrigation District (IID). The power interchanges between California and the Pacific Northwest and between California and the Southwest (Arizona, Nevada) are also significant determinants of the performance of the California Power Pool.

Assuming market incentives that support steady growth of PHEV sales over the next two decades and additional interest of early adopters, PHEVs in this area are postulated to comprise about 1 million of the area's private vehicles in 2030. The PHEV-30 model used in this study contains a 14 kWh Li-ion battery with approximately 8 kWh of usable operating range.[h] The additional 6 kWh was designed to provide safety margins from battery

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[h] Usable operating range could fall between 6-9 kWh depending on battery model configuration and vehicle size. The 8 kWh for a mid-size sedan was determined using the project team's modified PSAT model.

overcharge/ overwork and to account for anticipated AER degradation over ten years. PHEV batteries may be classified by either a blended mileage description (e.g., 100 mpg, 150 mpg), an ownership cost (sum of costs per mile for fuel and electricity), or combination of the two that demonstrates a battery size equivalence of a PHEV-30.

The majority of the older PHEV fleet in 2030 will only be equipped for charging at 110V, which restricts most PHEVs from V2G or commercial V2B capability. Still, PHEVs with only a 110V charger will be able to use the vehicle's battery and engine for camping, tailgating, or operating select home appliances in emergency situations or power outages (similar to current RVs). In 2030, 10% of the existing PHEV fleet (1% of the total vehicle fleet) will be equipped with dual 110/220V chargers and V2B or V2G capability. All new PHEV models sold in 2030 and beyond will have either a dual charger (both 110V and 220V capabilities) or a 220V charger. Hence, 110V-only chargers are expected to be phased out around this time.

PHEV chargers in the vehicle owners' homes will be separately metered with a time of use or other price- and time-responsive rate. An electronic controller will automatically delay charging until off-peak hours begin unless the driver chooses to override this feature by pushing a "Charge Now" button. The Phase 1 case study will analyze the effects of drivers that primarily charge their PHEV at night (off peak) in a garage or equipped parking facility but plug-in opportunistically for approximately 5% of post-morning commutes and 15% of post-evening commutes. Some parking facilities will be able to act as aggregators providing responsive loads and some degree of ancillary services in regulating the charging of 110V PHEVs.

Charger management systems will be in place to manage overall fleet charge load profiles. For example, a consumer may specify the hour by which the vehicle must be charged (e.g., "fully charged by 6 AM"), and smart meter technology will accommodate the request by scheduling the chargers on a feeder or in a neighborhood to provide a system "valley fill" in the utility load curve, avoiding unduly high locational or spot peaks. Alternatively, a charger's time clock could simply begin off-peak charging after a random time delay (1 to 30 minutes after off-peak rates commence) to avoid high needle peaks on the distribution system that would occur if the chargers were to all begin charging simultaneously.

A small portion (approximately 10%) of the 2030 PHEV fleet in addition to all new PHEVs sold after 2030 will have commercial V2B capability, which requires 220V charging capabilities. Most of these PHEVs will plug in at the workplace in exchange for permitting the building to regulate the vehicle charge/discharge in order to reduce its billing demand. Commercial V2B to reduce peak billing demand offers an easily-determined value and can be implemented in facilities with building energy management systems without very high additional investment in infrastructure. The occasional draw-down of the batteries for this value proposition is not expected to significantly affect battery performance or lifetime.

By 2030, it is assumed that most vehicles will be equipped with global positioning systems (GPS) capable of optimizing blended fuel economy by recognizing recurring trips or analyzing driver-entered destinations in combination with the drive train controller.

Anticipated fuel savings accrued by the owner using this efficient dispatch of the battery discharge and use of on-board fuel were included in this case study.
To validate and revise the specifics of this case study, members of the project team met with representatives of SCE, which includes a member of the Guidance and Evaluation Committee. Specific validations included confirmation of commuter driving distances in the Los Angeles metropolitan area to ensure that an appropriate battery capacity was chosen for analysis. SCE (currently working with Ford Motor Company, EPRI, and Johnson Controls on a large PHEV development, evaluation, and performance monitoring project), provided valuable insight on several case study assumptions.

The existing southern California utilities' power systems and CAISO provided the initial data for modeling the 2030 power system. The load forecasts, fuel price forecasts, and generation expansion plans for southern California were used to estimate the characteristics of the 2030 power system. However, the forecasted generation mix for 2030 was modified to incorporate a 30% RPS and expected improvements to power generation technologies, such as increased efficiencies and reduced emissions. In addition, input for price values and sensitivity ranges used the Energy Information Agency (EIA) Annual Energy Outlook 2008 (AEO2008) and Workshop projections, shown in Table 2.

Table 2: *Comparison of EIA projections and workshop predictions for 2030 range.*

	EIA Projections	Workshop Predictions	Sensitivity Range
Carbon "Tax" (2006 \$ / ton of CO_2)	-	30	0 – 50
Fuel Price (2006 cents / gal)	244.6	450	200 – 800
Electricity Rate[i] (2006 cents / kWh)	13.4	-	5 – 25 [j]
Ethanol Content	-	30	10 - 30%
All-Electric Range (mi)	-	-	15 – 30
Vehicle Weight Reduction	-	-	0 – 30%

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[i] End-Use Prices – Residential (California). No carbon tax included.
[j] Range includes a mixture of off-peak and on-peak rates

2.5. Modeling Requirements

Figure 3 below illustrates the summary of data flows that helped guide the Phase 1 testing process. Starting from the left of the diagram, "inputs" are fed into their designated "models" for analysis. Useful "outputs" from these models either fed back as additional inputs to complementary models or continued downstream as critical components of the overarching "macro business model" (MBM). Results from the MBM will ultimately be used to project the percentage of consumers that would buy the PHEV model given the Phase 1 baseline constraints. For a more detailed description of this data flow diagram and its individual models and applications, access the PHEV Value Proposition Phase 1, Task 3 Report at www.sentech.org/phev.

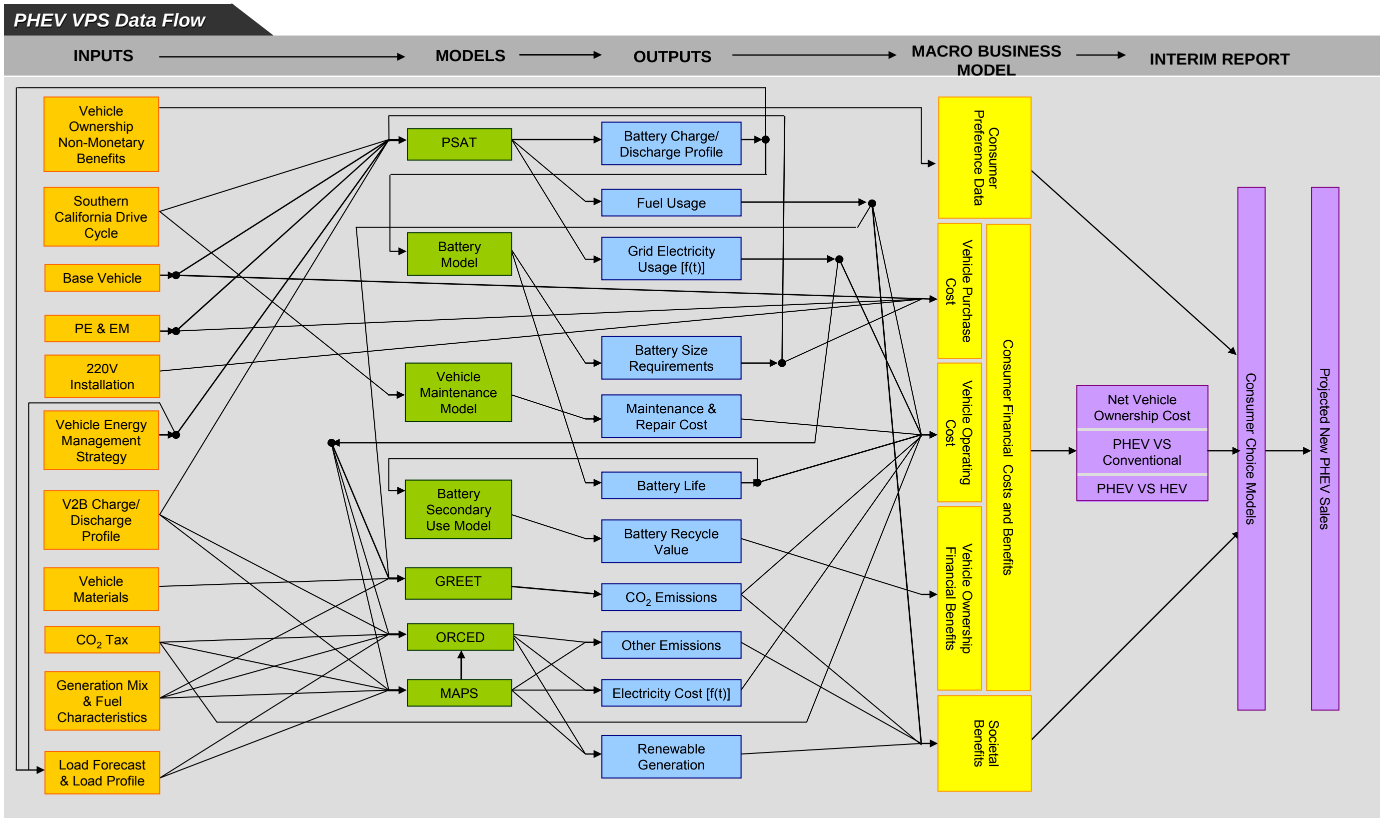

Figure 3: *Network of data flow used in Phase 1 case study analysis.*

Models shown in Figure 3 were strategically selected because they provide the required information for analyzing the seventeen value propositions studied in Phase 1. Table 3 below lists all the value propositions along with the lead investigator(s), modeling requirements, applicable output, and application of output for each value proposition.[k] Each value proposition is individually broken down in greater detail in the Phase 1, Task 3 Report.

Table 3: *Phase 1 value propositions and modeling approach for each.*

VALUE PROPOSITION	LEAD INVESTIGATOR(S)	MODELING REQUIREMENTS	APPLICABLE OUTPUT	USE OF OUTPUT
Vehicle Ownership Benefits				
1. Fuel cost savings (with GPS-enabled fuel optimization dispatch)	Sentech, Inc.	Powertrain System Analysis Toolkit (PSAT)	Blended mileage operating cost	Quantify PHEV operating cost savings
2. Tailgate/camping, limited household appliance backup (residential V2B)	Sentech, Inc.	Consumer Preference	Associated level of value for consumer	Assign a monetary value or estimated market size
3. Opportunistic charging from any outlet	Sentech, Inc.	Consumer Preference	Associated level of value for consumer	Assign a monetary value or estimated market size
4. Reduced vehicle maintenance costs	EPRI	Maintenance Model	Expected reduction in maintenance cost with PHEV	Quantify the amount of savings (if any)
5. Convenient charging locations (e.g., at airports, municipalities, etc.)	Sentech, Inc.	Consumer Preference	Associated level of value for consumer	Assign a monetary value or estimated market size
6. Battery recycling credit	Sentech, Inc.	Second Use Battery Report	Estimated salvage value of battery	Establish recycling credit to consumer
7. Recognition of “social” responsibility	Sentech, Inc.	Consumer Preference	Associated level of value for consumer	Assign a monetary value or estimated market size
Societal Benefits				
8. Reduced petroleum imports	Sentech, Inc.	PSAT, Oil Generation in Cal.	Reduction in petroleum use per vehicle	Address national strategic goals

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[k] Due to time constraints, V2G value propositions included in the Phase 1 Task 2 report have been delayed to Phase 2 to ensure thorough analysis.

9. Emissions reduction	Sentech, Inc.	Greenhouse gas Regulated Emissions, and Energy use in Transportation model (GREET)	“Well-to-Pump” and “Pump-to-Wheel” greenhouse gas (GHG) emissions (with and without PHEV fleet), and tailpipe emissions for both conventional and PHEV vehicles	Quantify reduction in emissions
Utility Benefits				
10. Responsive load – utility control of charger	ORNL; Sentech, Inc.	Load forecasts for California; load profile changes	Reduced commercial building billing demand charge or “time of use”-based electric billing	Assign a monetary value to proposition
11. Increased use of renewable energy in generation mix	ORNL; GE	Oak Ridge Competitive Electricity Dispatch model (ORCED), Multi-Area Production Simulation (MAPS)	Determine if higher off-peak loads reduce renewable energy curtailment	Determine if PHEVs can help meet RPS
12. Carbon “tax” equivalent	ORNL; GE; Sentech, Inc.	PSAT, ORCED, MAPS	Change in fuel price and electricity price	Calculate PHEV operating costs vs. conventional operating costs
13. Utility cost savings (capital or production) in $/kWh for serving PHEVs	ORNL; GE	MAPS, ORCED	Change in cost of electricity for SCE (MAPS) and CAISO (ORCED)	Quantify PHEV operating cost savings
14. Time dependent electricity pricing for PHEV owners	Sentech, Inc.; ORNL	Cost of vehicle operations	Cost to charge PHEV	Assign a monetary value to proposition
Commercial Building Owner Benefits (applicable only to PHEVs with V2B capability)				
15. Emergency back-up power for commercial facility (commercial V2B)	Sentech, Inc.; ORNL	Use published reports on costs of outages	Value of backup power	Assign a monetary value to proposition
16. Responsive load - V2B capability	Sentech, Inc.; ORNL	Analysis of utility load profiles; battery model	Determine what must be done to prevent spot/needle peak loads	Modify load curve used for MAPS and ORCED
17. Reduced billing demand for commercial building (commercial V2B)	Sentech, Inc.; ORNL	Commercial building load profile from CA; vehicle model combo	Reduced commercial building billing demand charge	Assign a monetary value to proposition

2.6. Construction of Macro Business Model

Once all desired outputs were obtained from each model, they were entered into the MBM comprised of the six primary components briefly described below. Phase 1 case study results for each of these components are documented in Section 3.

2.6.1. Consumer Financial Costs and Benefits

In this section of the MBM, the overall costs and benefits of owning and operating a PHEV are weighed to estimate the comprehensive value to the owner. As a reference for comparison, the value of owning and operating an HEV and conventional vehicle were also estimated using this model. The three basic components that feed into consumer financial benefits are:

1. Vehicle purchase costs (e.g., base vehicle cost, power electronics & electric machines, battery cost, home circuit installation for recharging),
2. Vehicle operating costs (e.g., fuel usage, grid electricity usage, battery longevity, carbon tax, maintenance/repair costs), and
3. Vehicle ownership financial benefits (e.g., battery recycling credit)

2.6.2. Consumer Preference Data

Phase 1 case study results will be provided to specific national laboratories and universities that have developed in-house consumer preference models. These models take into accounts both qualitative and quantitative characteristics of a vehicle that may play a role in a consumer's purchase decision. The output of these models will provide guidance on the estimated value, or worth, of PHEV attributes and potentially help predict what percentage of car buyers would purchase a particular vehicle as a result. Qualitative attributes of interest include emergency back-up power, convenient charging locations, and the ability to plug in from any outlet. These attributes contribute to additional value needed for PHEVs to reach the anticipated 10% market penetration by 2030. Results from these consumer preferences models will be included in the follow-on sensitivity analysis of the southern California case study scheduled as part of Phase 2.[1]

2.6.3. Societal Benefits

The nationwide effects that are expected to result from a large PHEV fleet are accounted for in the social benefits section of the MBM. These non-monetary values will help to significantly lessen the magnitude of several negative impacts traditionally linked to conventional vehicles. For instance, reduced fuel usage will help decrease the country's dependence on foreign oil, thus strengthening national security. Similarly, reduced GHG and other emissions from PHEVs may ultimately improve air quality and climate change efforts relative to conventional vehicles. Finally, increased amounts of PHEVs plugged in during off-peak hours have the potential to increase the percentage of renewable energy used in the generation mix, which may reduce the costs (e.g., compared to installation of fixed energy storage) needed for utilities to meet state RPS targets.

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[1] Data source: University of Michigan Transportation Research Institute (UMTRI); National Renewable Energy Laboratory (NREL); University of California, Davis

2.6.4. Utility Benefits

Several potential benefits to the utility were investigated in the Phase 1 case study. Interactions between the semi-dispatchable PHEV recharge loads and the daily operational characteristics of a regional grid were observed to determine cost savings to the utilities (capital or production). The operational issues of economic dispatch of generation assets and loading of generation assets were also analyzed. The generation type, amount, cost, and associated emissions to provide the PHEV requirements based on the hourly charging cycles were evaluated. The Phase 1 analysis did not include additional capacity development to respond to PHEV demands. (One of the advantages of PHEVs is that with off-peak charging, little or no additional capacity is needed.) The Phase 2 analysis can include some dedicated renewable power constructed in coordination with PHEV market penetration. This will allow an evaluation of renewable expansion in conjunction with PHEVs.

2.6.5. Commercial Building Owner Benefits

Commercial building owners may use V2B to utilize commuter vehicles driven to urban areas to reduce billing demand for office buildings. The charge/discharge cycle of a typical PHEV can be modified to recharge it immediately upon arriving at “work,” discharge to some extent during building peak period, and recharge as much as possible during minor “valleys” of the building’s load profile. The value of this to the commercial building, in terms of 1) reduced billing demand, 2) reduced energy costs under time of use rates, and/or 3) incentive payments from the utility under utility peak reduction programs has been calculated from published California utility rate schedules, escalated to expected 2030 levels. Commercial building owners may also greatly benefit from emergency back-up power available from a small PHEV fleet.

2.6.6. Battery Alternative Design and Ownership Options

Battery cost may be the single largest impediment to large scale commercialization of PHEVs. Several approaches to reducing this cost for the consumer have been proposed. These include incorporating a less expensive battery with a reduced energy storage system capacity and/or having a third party (someone other than the auto manufacturer or the consumer) own the batteries available for lease to the consumer. Options for alternative battery ownership options have been partially explored in Phase 1, and investigation will be continued by the project team in future phases.

2.7. Vehicle Parameters

For the initial "baseline" scenario in Phase 1, three vehicle types (conventional vehicle, HEV, and PHEV-30) were modeled and simulated. Table 4 provides a summary breakdown of materials distribution and powertrain properties for each of these vehicle types. A complete breakdown of the established vehicle parameters is provided in Appendix A. The basis for cost calculations of individual vehicle components are listed in Table 5 followed by basic consumer driving and ownership assumptions in Table 6.

Table 4: *Basic vehicle modeling parameters for mid-size sedan in 2030*

	Conventional	HEV	PHEV-30
Mass			
Glider Mass (kg) [m]	693	693	693
Engine/Transmission/Final Drive/Wheels (kg)	441	374	374
Power Electronics and Electric Machine (kg)	0	44	44
Energy Storage (kg)	0	50	124
Fuel Subsystem (kg)	58	48	48
Total Vehicle Mass (kg)	1192	1209	1283
Total Vehicle Mass w/ 136 kg Cargo (approx. two passengers)	1328	1345	1419
Energy and Power			
Battery Energy (kWh) [n]	-	-	14
Battery Power (kW) @ 95% state of charge (SOC)	-	73	-
Engine Power (kW)	110	50	50
Motor Power (kW)	-	55	55

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[m] Glider mass = Vehicle– (Engine+Motor+Batteries+Transmission+Final Drive+Fuel Storage+Wheel). Based on 30% reduction in current glider mass of 990 kg as per DOE GPRA Study Results. Additional analysis without this weight reduction has been completed for comparison purposes.

[n] Only approximately 8 kWh of the 14 kWh storage is considered usable capacity in this study's battery model.

Table 5: *Basis for vehicle cost calculations for mid-size sedan in 2030 (2008 $)*

	Conventional	HEV	PHEV-30
Manufacturer’s Suggested Retail Price (MSRP)[2]	$21,390	-	-
Glider	Conventional MSRP – Conventional Powertrain		
Powertrain [o]	Engine + Transmission + Motor/Inverter* + Battery* + Charging Plug*		
Engine [3]	$14.5 x kW + $531		
Transmission [4]	$12.5/kW		
Motor/Inverter [4]	-	$8/kW	
Battery [4]	-	$20/kW	$200/kWh
Charging Plug [3]	-	-	$380 + Baseline Inverter

* - If applicable

Table 6: *Basic consumer ownership and driving habits of a mid-size sedan in 2030*

	Conventional	HEV	PHEV-30
1st Length of Ownership (years)	10		
Annual Vehicle Miles Traveled	15,425		

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[o] A retail markup of 100% will be applied to all powertrain components.

3. PHASE 1 CASE STUDY RESULTS

3.1. Consumer Financial Costs and Benefits

While PHEVs are expected to have a significant price premium over conventional vehicles and HEVs in 2030, they may still result in net savings to the vehicle owner through reductions in operating cost and exclusive ownership benefits. Anticipated technology improvements in the power electronics and electrical machinery (PE&EM), and advanced battery technologies as stated in DOE's Vehicle Technologies Multi-Year Program Plan have been accounted for in the HEV and PHEV models[d], resulting in a more robust scenario for each vehicle type. The three dimensions of vehicle ownership investigated in this case study are *vehicle purchase costs*, *vehicle operating costs*, and *vehicle ownership financial benefits*.

3.1.1. Vehicle purchase costs

3.1.1.1. Conventional Vehicle

The basic architecture of the conventional vehicle is the least complex of the mid-size sedans analyzed in this case study, comprised of only a glider[p], ICE, and transmission. As shown in the cost breakdown in Figure 4, the estimated purchase cost for this conventional vehicle in 2030 is approximately $21,400 (using the cost equations in Table 5). A simple schematic of a conventional vehicle powertrain is also provided below. See Appendix B for all vehicle purchase cost calculations.

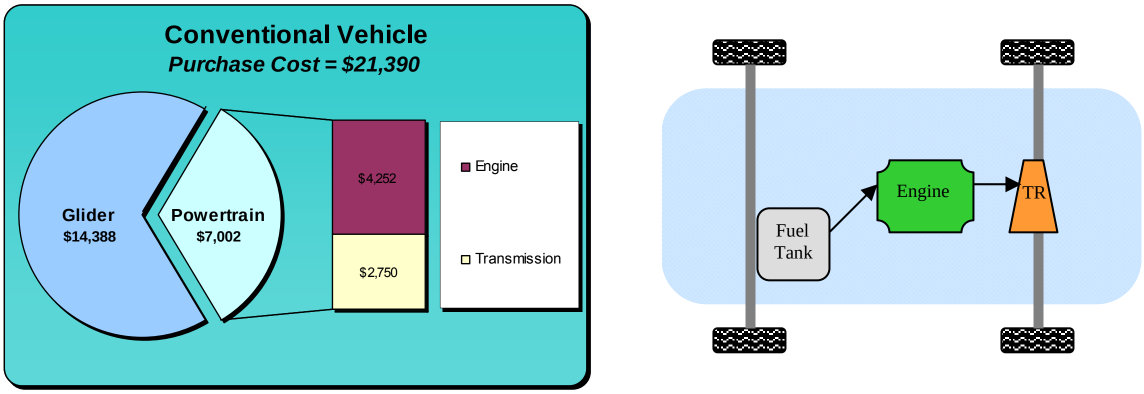

Figure 4: *Breakdown of component costs (left) and schematic of powertrain (right) for conventional vehicle.*

3.1.1.2. HEV

The basic architecture of an HEV is a combination of a conventional ICE and an on-board rechargeable energy storage system (RESS). The integration of an ICE with a RESS needed to operate an HEV requires the addition of a motor/inverter and battery pack. Since the battery pack does provide an additional source of power, a smaller engine and fuel tank are commonly used relative to a conventional vehicle. In addition, a reduced engine size was used in the HEV for modeling purposes to maintain a consistent

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[p] Glider = vehicle without the powertrain

performance level among the three vehicle types simulated in this study. As shown in the cost breakdown in Figure 5, the estimated purchase cost for this HEV in 2030 is approximately $22,600 (using the cost equations in Table 5). A simple schematic of the parallel hybrid powertrain analyzed in this case study is also shown below. See Appendix B for all vehicle purchase cost calculations.

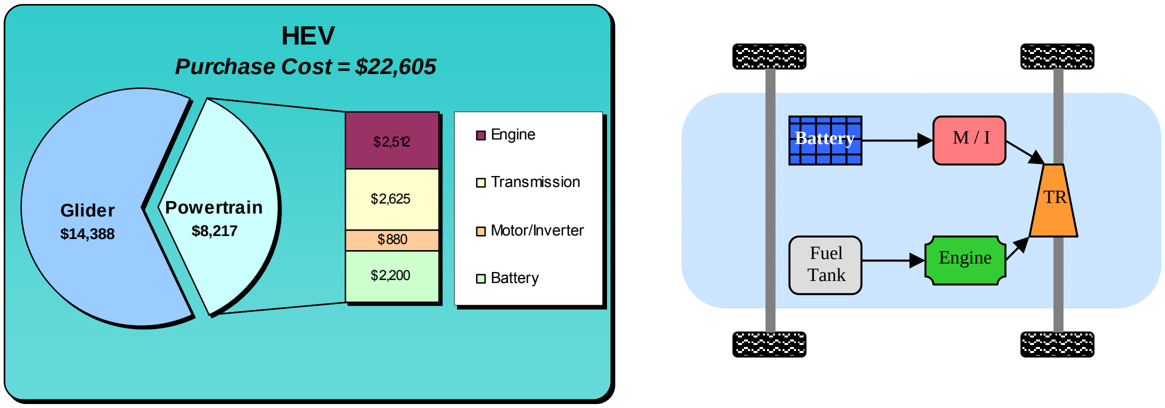

Figure 5: *Breakdown of component costs (left) and schematic of powertrain (right) for HEV.*

3.1.1.3. PHEV-30

The PHEV architecture is differentiated from an HEV basic architecture by its ability to further displace fuel usage by charging off-board electrical energy at home through the electric utility grid. To accommodate the increased dependence on electric power while maintaining an appropriate vehicle weight, the PHEV uses a battery pack with a larger capacity and a smaller ICE and fuel tank. Similar to this study's HEV, an engine of reduced size was used in the PHEV for modeling purposes to maintain a consistent performance level among the three vehicle types simulated in this study. Also, an inverter integrated charging plug is needed to connect the enhanced battery pack to a standard electrical socket for recharging. As shown in the cost breakdown in Figure 6, the estimated purchase cost for this PHEV in 2030 is $26,700 (using the cost equations in Table 5). A simple schematic of the PHEV powertrain analyzed in this case study is also shown below. See Appendix B for all vehicle purchase cost calculations.

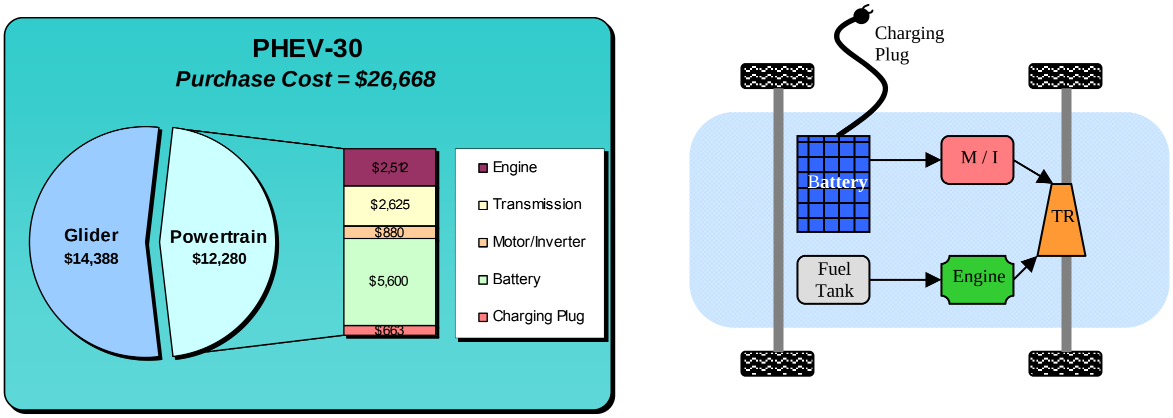

Figure 6: *Breakdown of component costs (left) and schematic of powertrain (right) for PHEV.*

3.1.1.4. Total Vehicle Purchase Costs

Figure 7 below displays the overall vehicle purchase cost differences between each vehicle type in 2030. Current vehicle purchase costs are included to provide a frame of reference for anticipated technology advancements (particularly in advanced batteries) and economies of scale over the next two decades (see Appendix B for 2008 vehicle cost calculations). For purposes of this study, the price of a 2030 conventional vehicle has been held constant to demonstrate individual component cost reductions expected in HEVs and PHEVs. However, an incremental cost for all 2030 vehicles is likely to accommodate a 30% reduction in vehicle weight and fuel efficiency of 35 mpg. With that said, the transmission and engine components are believed to be near maturity, so no relative cost reductions are expected from these components in future years.

For this study, conventional vehicles exhibit the least expensive initial cost of $21,400, which is not expected to vary significantly through 2030. HEVs, however, are expected to decrease in cost by $3,630 down to $22,600 due to improvements in PE&EM. PHEVs will experience the most dramatic cost reduction from $52,700 in 2008 to $26,700 in 2030. With these cost reductions, HEVs and PHEV-30's are expected to have a price premium of approximately $1,200 and $5,300, respectively, relative to conventional vehicles in 2030. Aligning closely with Workshop forecasts, PHEVs are anticipated to have a $6,000 price premium over conventional vehicles in 2030.

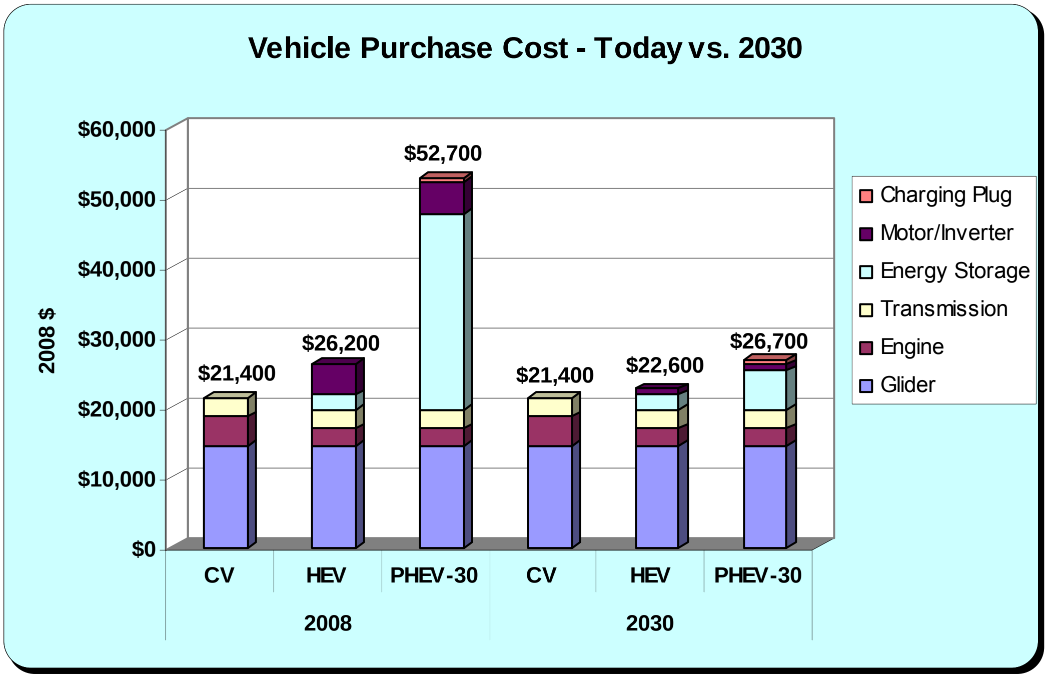

Figure 7: *Overall vehicle purchase cost comparison for conventional vehicles, HEVs, and PHEVs produced in both 2008 and 2030.*

3.1.2. Vehicle operating costs

In the Phase 1 case study, the vehicle operating costs for conventional vehicles, HEVs, and PHEVs are comprised of fuel (liquid and electricity), maintenance, battery replacement, and a carbon tax. More detailed information on the operating cost analysis is provided in Appendix C.

3.1.2.1. Fuel (Liquid and Electric)

HEVs have the benefit of an additional electric motor to aid the engine during hard acceleration, high speed or other high load conditions. In addition, energy that would typically be lost to heat can be captured by regenerative braking. These all contribute to a reduction in fuel consumption. If so designed, the control system can operate the motor such that the engine will operate at or near its most efficient operating region or in some instances not at all. A PHEV has the same advantages of the HEV with the addition of greater battery capacity enabling substantially longer periods of electric-only operation, thus further reducing the fuel consumption of the vehicle.

A pre-transmission parallel hybrid powertrain architecture was selected in congruence with the powertrain configuration used to develop DOE's Government Performance and Results Act (GPRA) of 1993 outputs at the time this study was initiated.[5] While a split hybrid system may be more efficient, it requires the expense, weight, and complexity of a planetary gearbox as well as an additional electric machine and associated power electronics. Vehicle components were sized based on DOE's performance requirements and GPRA study results for 2030. This incorporates component efficiency improvements as well as light-weighting projections.

The drive cycles were based on commonly accepted standardized drive schedules. The cycles were combined to reflect common driving habits, average commute time, and annual distance traveled for the southern California region. Due to time restraints, a drive cycle based on actual driving data from the analysis region was not created, but may be pursued in future phases. However, based on preliminary discussions about the potential drive data that may become available, the characteristics of the drive cycles chosen appear to be representative of how an average commuter operates his or her vehicle in the southern California area.

The average amount of liquid fuel (E30) consumed by a single PHEV-30 was calculated using PSAT (see Appendix D for detailed calculations). Using an E30 price of $4.50/gal (2008 $), PHEV-30s reduce liquid fuel costs over conventional vehicles by 80% (Figure 8). This translates to over $16,000 less that PHEVs will spend on gasoline. Likewise, PHEVs use 70% less E30 than HEVs, resulting in approximately $9,500 in liquid fuel savings for the initial PHEV owner. As previously mentioned, the PHEV used in this study has an assumed glider weight reduction of 30% and consumes an average E30 blend. For comparison purposes, the same PSAT simulation was also performed on a PHEV that exhibits no weight reduction between now and 2030 and still consumes today's common E10 blend. Fuel and electricity consumption results of this comparison analysis are included in Appendix D.

Of course, the dramatic savings in liquid fuel seen in PHEV-30s is partially offset by less expensive electricity needed to provide the required additional energy. To determine the cost per kWh of the electricity consumed by PHEVs, the regional generation mix data is needed. According to the AEO2008 reference scenario, California's mix of electricity capacity for the grid will be roughly 58% from central gas-fired technologies (combined cycle, steam and combustion turbine), with the remaining from coal (5%), nuclear (6%), renewables (23%), and distributed generation (3%) by 2030. Generation percentages from the different technologies depend on the price of fuels and any CO_2 permit prices. However, in most scenarios the power plants that set the wholesale price, especially when PHEVs would be charging, are gas-fired combined cycle plants.

Using the efficiencies for the different plants in the region and a natural gas price of \$14/mmBtu (double of the AEO2008 reference price), the average wholesale price of electricity during the off-peak hours is 8.3¢/kWh (this is prior to applying a carbon tax to the electricity rate). In addition, a 10¢/kWh for delivery services is included, similar to the price that some California utilities use for their current electric vehicle rates. Since actual time-differentiated electricity rates could not be obtained for the southern California region (e.g., peak rates), an average off-peak electricity rate of \$0.183/kWh was used in this study. More detailed information is included in Appendix E.

The average annual amount of electricity used by a single PHEV-30 was simulated in PSAT to be approximately 2,900 kWh, adding approximately \$530 to the PHEV-30 annual operating cost. This additional cost still results in significant savings over the lifetime of the vehicle relative to conventional vehicles and HEVs. Using an E30 price of \$4.50/gal and an electricity rate of \$0.183/kWh, the lifetime combined fuel (liquid and electric) costs for the PHEV-30 is roughly \$9,600. As shown in Figure 8, this offers an operating cost savings of about \$11,000 and \$4,200 relative to conventional vehicles and HEVs, respectively.

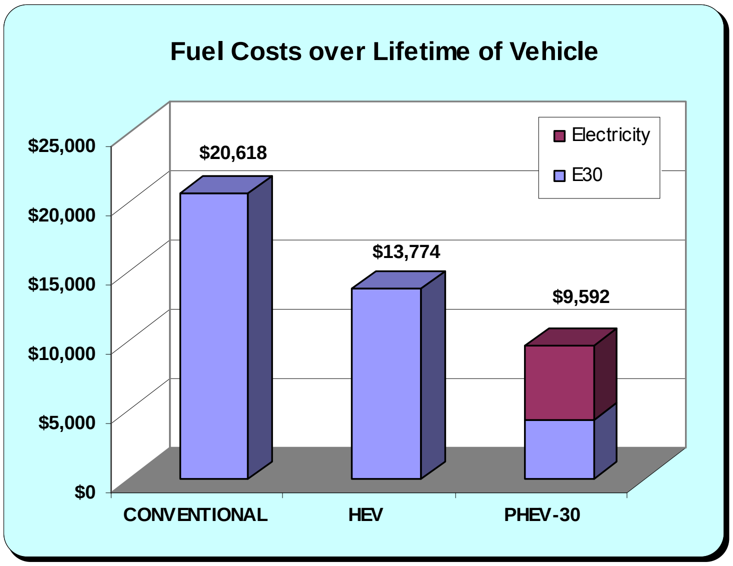

Figure 8: Effects of varying E30 and electric rates on the overall net vehicle ownership of ten years.

Figure 9 below demonstrates how the net ownership cost of each vehicle type is affected by fluctuating E30 prices and electricity rates. With all other parameters held constant, PHEVs are the most economic choice compared to conventional vehicles as long as E30 prices exceed $2.22 per gallon and electricity rates are below $0.47/kWh, including transmission and distribution (T&D). HEVs appear to be the most financially responsible purchase unless E30 prices exceed $3.72 per gallon and electricity rates are below $0.24/kWh, in which case PHEVs become most financially appealing.

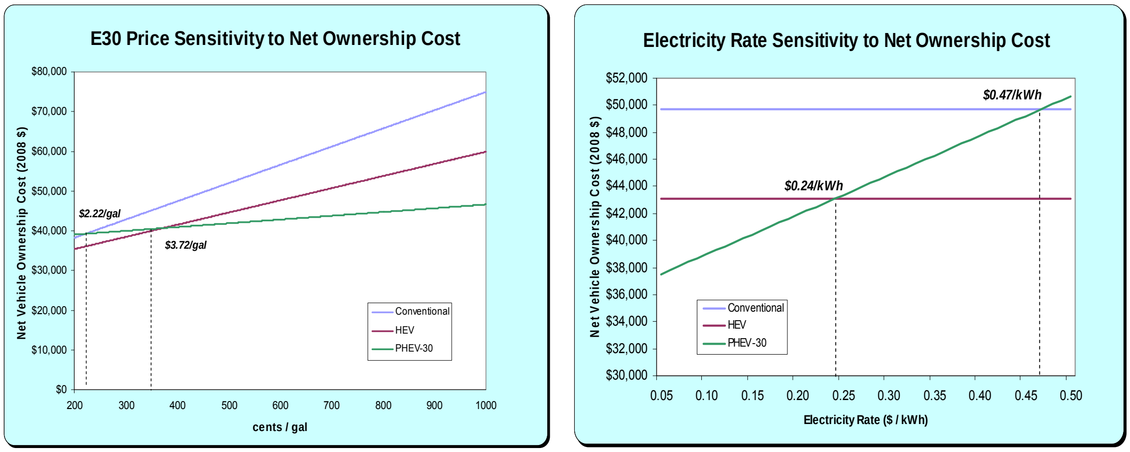

Figure 9: *Effects of varying E30 and electric rates on the overall vehicle lifetime of ten years.*

3.1.2.3. Maintenance Costs

PHEVs have been speculated to have lower scheduled maintenance costs relative to conventional vehicles and HEVs for several reasons. First, PHEV engines are running for a lower percentage of the vehicle's operating time; therefore they may have longer intervals between oil changes and air filter replacements. Second, regenerative braking on HEVs and PHEVs reduces brake wear and the need for brake replacements. These costs contribute significantly to a vehicle's overall operating costs over its lifetime. The lifetime scheduled vehicle maintenance costs are shown in Figure 10, extrapolating values from EPRI's 2001 study titled "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options."[c] Values from this report have been inflated by 21% to match 2008 dollars.[6]

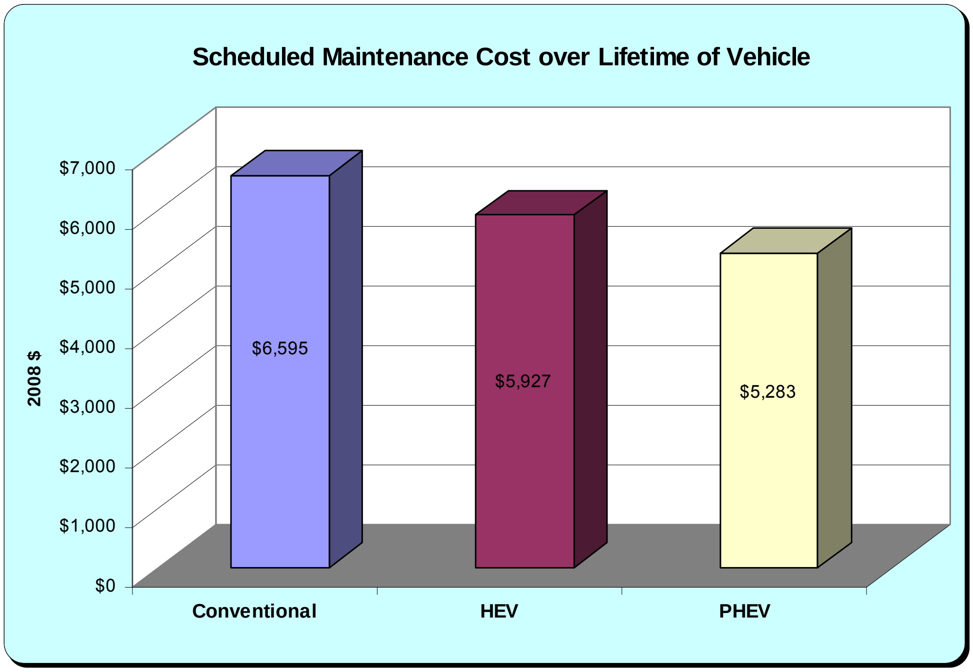

***Figure 10:** Cumulative scheduled maintenance costs for conventional vehicles, HEVs, and PHEVs over ten year vehicle lifetime.*

Due to the absence of unscheduled maintenance data (e.g., unexpected repairs), an accurate cost comparison between each vehicle type could not be performed. However, the increased number of powertrain components susceptible to failure is greater in PHEVs than in HEVs or conventional vehicles; therefore, it is not unreasonable to assume that *unscheduled repair costs* will be higher relative to conventional vehicles, potentially canceling out cost savings from scheduled maintenance resulting from PHEVs.

3.1.2.4. Battery Replacement Cost

The PHEV batteries simulated in this study have a life expectancy of ten years, which is also the anticipated life expectancy of the vehicle. Therefore, unless the battery proves to be faulty, the vehicle owner will not be required to replace the battery. If a battery malfunctions within its life expectancy, a warranty offered by some party (e.g., auto manufacturer, battery manufacturer, third party) is assumed to cover this expense. Without such a warranty, a major barrier to the successful market introduction of PHEVs would result. A thorough summary of this case study's battery analysis is provided in Appendix F.

3.1.2.5. Carbon Tax

Participants in the Workshop's Breakout Session 5 forecasted that a carbon tax would be instituted in the transportation sector by 2030, which is expected to be regulated on an international basis. For the Phase 1 simulation, a value of $30/ton (2008 $) of CO_2 (within the range recommended by the breakout session group) was used. To determine the resulting increase in operating cost of each vehicle type, this carbon tax was applied to CO_2 emissions simulated in GREET. (Additional information on the GREET GHG analysis and carbon tax calculations are provided in Appendix G.) Consequently, the cost of owning and operating a conventional vehicle, HEV, and PHEV-30 over ten years increased by approximately $1,100, $750, and $850, respectively. Since PHEVs emit less CO_2 than conventional vehicles (see Section 3.2.2.), PHEV owners would save approximately $250 during the vehicle life. However, PHEV owners would likely owe $100 more than HEV owners over the lifetime of the vehicle, primarily because the source of emissions associated with the electricity used in PHEV is higher than the larger volume of E30 used in HEVs. As noted in Appendix G, PHEVs that use E10 blend instead of E30 blend that anticipate no weight reductions between now and 2030 actually result in lower CO_2 emissions than HEVs with the same modifications. In this case, PHEV owners would consequently pay less in carbon tax over the lifetime of the vehicle.

The sensitivity chart in Figure 11 demonstrates the change in net vehicle ownership costs for each vehicle type as carbon tax ranges from non-existent to a charge of $150/ton of CO_2 emissions. This sensitivity analysis does not include changes in grid generation mix as a result of the carbon tax as it is beyond the scope of this project. An analysis that identifies the effects of a carbon tax on a region's generation mix would, indeed, be a valuable asset to this and future PHEV case studies.

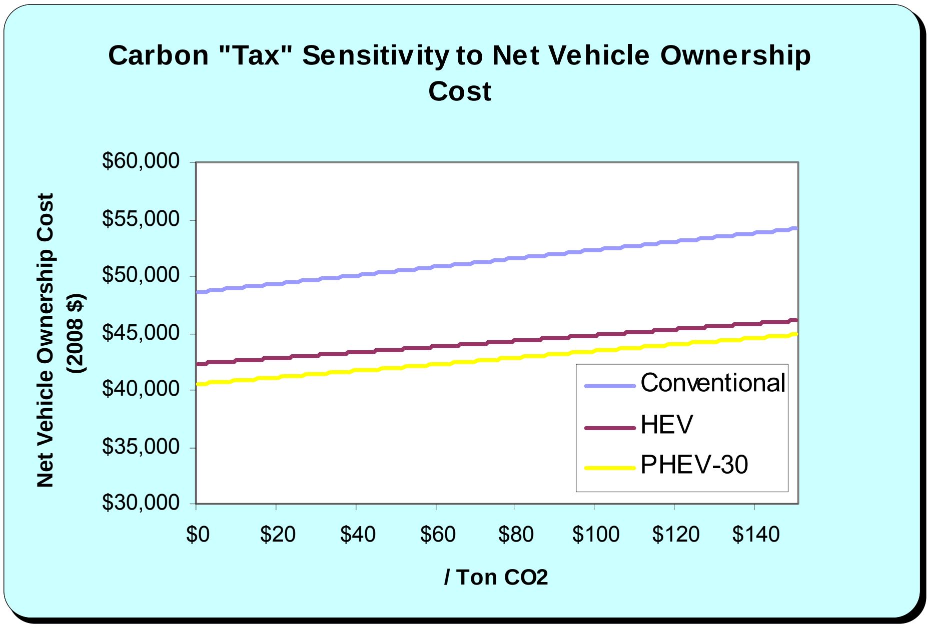

Figure 11: *Effects of varying carbon tax amounts on the overall net vehicle ownership over ten years.*

2.1.2.6. Total Vehicle Operating Cost

As demonstrated in Figure 12, a PHEV-30 presents significant savings in operating costs over its lifetime. A PHEV-30 can save nearly $13,000 relative to the conventional vehicle and over $5,000 relative to the HEVs over the lifetime of the vehicle (in 2008 $).[q] The most dramatic savings that PHEVs offer over conventional vehicles are achieved by

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[q] Similar operating cost savings would be accrued if vehicles continue to use an E10 blend and do not display any reduction in weight. (see Appendix C).

replacing the majority of liquid fuel (E30) with more cost-efficient electricity stored in its battery. Similarly, HEVs are able to decrease operating costs by supplementing a large percentage of liquid fuel with on-board stored electrical energy.

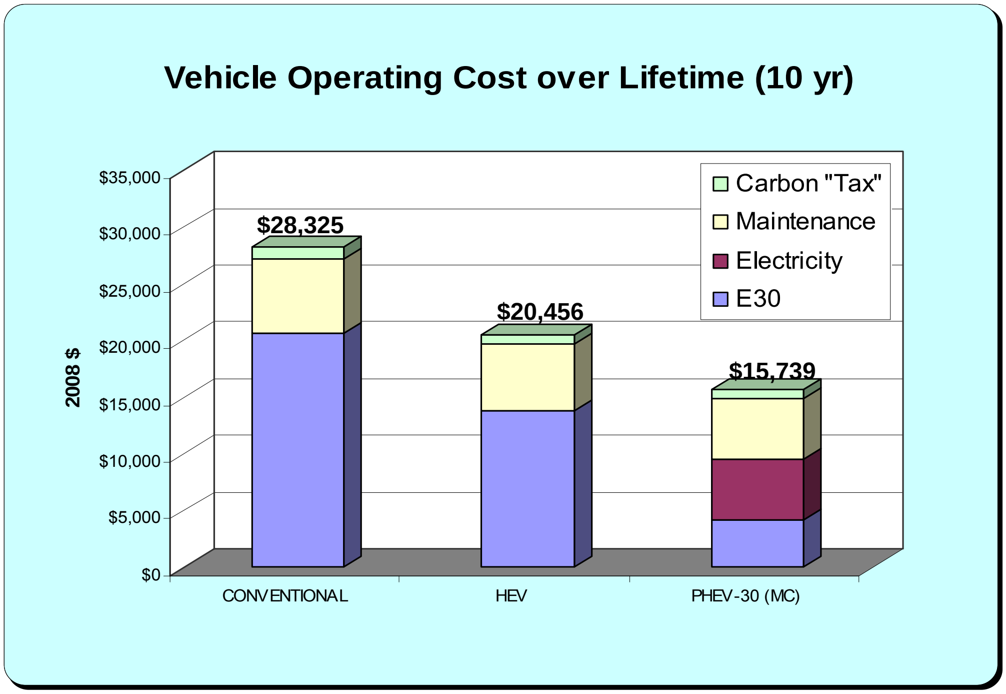

***Figure 12:** Overall vehicle operating cost comparison for conventional vehicles, HEVs, and PHEVs in 2030 over the lifetime of the vehicle in southern California.*

3.1.3. Vehicle Ownership Financial Benefits

3.1.3.1. Battery Recycling Credit

To recover a portion of the vehicle purchase and operating costs, a recycling credit available to PHEV owners was investigated for Li-ion batteries that have reached end-of-life, meaning the battery can no longer provide 80% of the energy (needed for vehicle range) or 80% of the peak power (needed for acceleration) of a new battery.[7] in this study, PHEV batteries are guaranteed to exceed 80% (7.8 kWh) for at least ten years, or approximately 150,000 miles. At ten years (vehicle end-of-life), PHEV owners may salvage their PHEV batteries in exchange for a potential recycling credit. A recent report published by Sandia National Laboratories (SNL) estimated the value of a 1 kWh battery with 90% charging efficiency to have a worth of $32 annually for arbitrage purposes.[8] Therefore, the value of this study's battery of 7 kWh at end of life would equate to roughly $225 annually.[r] This is also consistent with a major utility's estimate of end-of-use Li-ion battery value.

In this case study, for convenience, a battery is assumed to remain in working order for an average of five to ten years after vehicle end-of-life; therefore, its cumulative value to

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[r] Assuming 7.8 kWh of power remains at the beginning of secondary use, a 0.2 kWh/yr degradation rate over ten years would result in a 7 kWh average power during secondary use.

the secondary owner would likely be in the range of approximately $850-1250 (NPV). Therefore, an average battery recycling credit was estimated to be $1000 to the PHEV owner to be collected upon salvage approximately ten years after initial vehicle purchase.

3.2. Consumer Preference Data

The preliminary results of the Phase 1 case study analysis have been provided to ORNL and the University of Michigan Transportation Research Institute (UMTRI) for further analysis specific to consumer preferences. Researchers at these facilities will use extensive survey data and other tools to help estimate the value, or worth, of the following value propositions:

1. Tailgate/camping, limited household appliance backup (residential V2B)
2. Opportunistic charging from any outlet
3. Convenient charging locations (e.g., at airports, municipalities, etc.)
4. Recognition of "social" responsibility

These values will help estimate the percentage of consumers who would purchase a vehicle with these attributes. These attributes contribute to additional value needed for PHEVs to reach the anticipated 10% market penetration by 2030. Results ORNL and UMTRI will be included in the follow-on sensitivity analysis of the southern California case study as part of Phase 2.

3.3. Societal Benefits

3.3.1. Reduced Petroleum Imports

As demonstrated in Fuel Costs (Section 3.1.2.1.), PHEVs consume significantly less fuel than either conventional vehicles or HEVs, playing a vital role in reducing petroleum imports. The transition to an E30 fuel blend also translates to a larger percentage of fuel produced domestically, which is in accordance with The President's Biofuels Initiative that requires a 30% displacement of transportation fuel consumption through biofuels by 2030.

Phase 1 case study results show that, on average, a single PHEV-30 will consume approximately 95 gallons of E30 blend fuel annually. Since 70% of this fuel is gasoline, it equates to approximately 66 gallons of gasoline, or 3.4 barrels of crude oil, consumed annually per PHEV-30. This is in comparison to 322 and 214 gallons of gasoline consumed annually by individual conventional vehicles and HEVs each year, respectively. For this case study, 60% of the fuel saved is assumed to have been produced from imported oil. Assuming that this percentage remains constant through for the next two decades, the southern California fleet of 1 million PHEV-30s in 2030 could reduce imported oil by roughly 153 million gallons of gasoline annually (if the PHEV fleet substituted for conventional vehicles) or 90 million gallons of gasoline annually (if the PHEV fleet substituted for HEVs). See Appendix D for detailed calculations. For comparison purposes, Appendix D also includes petroleum use data for the three vehicle types that each fail to achieve any vehicle weight reduction or increase ethanol use between now and 2030.

3.3.2. Reduced GHG Emissions

GHG and tailpipe emissions is affected by many factors, including the choice of fuel (reformulated or not, ethanol included or not), baseline fuel economy of the gasoline vehicle, the design of the hybrid system itself (duty cycles on gasoline and electricity), and the mix of electric power generation. If, for example, all electricity were produced by nuclear power, then GHG emissions would be near zero for the electric drive portion of the vehicle's duty cycle. By comparison, generating electricity totally from coal would render an entirely different scenario with regard to GHG emissions.

The GREET model was used to assess these subtleties and to estimate and compare the "Well-to-Pump" and "Well-to-Wheel" GHG emissions of conventional vehicles, HEVs, and PHEVs cases. The GREET model, developed by ANL, is widely used among automotive technologists – researchers and industry – to estimate energy use and emissions for various light-duty vehicle scenarios. The model contains a large number of data and assumptions about production of fuel from oil and renewable resources, the delivery of those fuels, and their end use in vehicles. This data is in spreadsheet form that uses a Graphical User Interface for the user to input all of the assumptions for the user's own situation to be modeled.

The GREET model was run for a scenario representing the expected situation in southern California in 2030. Figure 13 provides a basic comparison of CO_2 and GHG emissions between the three vehicle types and also compares total energy used between the three vehicle types. Relative to conventional vehicles, PHEVs reduce both CO_2 emissions and overall GHG emissions by nearly one quarter primarily due to less petroleum burned. PHEVs also use approximately 40% and 10% less total energy compared to conventional vehicles and HEVs, respectively. CO_2 and GHG emissions for PHEVs and HEVs appear to balance out, depending on the ethanol blend used and the weight of the vehicle. When an E30 blend is used on a lighter weight vehicle (as shown below), PHEV emissions are slightly higher. When an E10 blend is used on a vehicle of traditional weight, however, HEVs have slightly higher emissions. See Appendix G for detailed assumptions calculations for both of the GREET analyses run for this study.

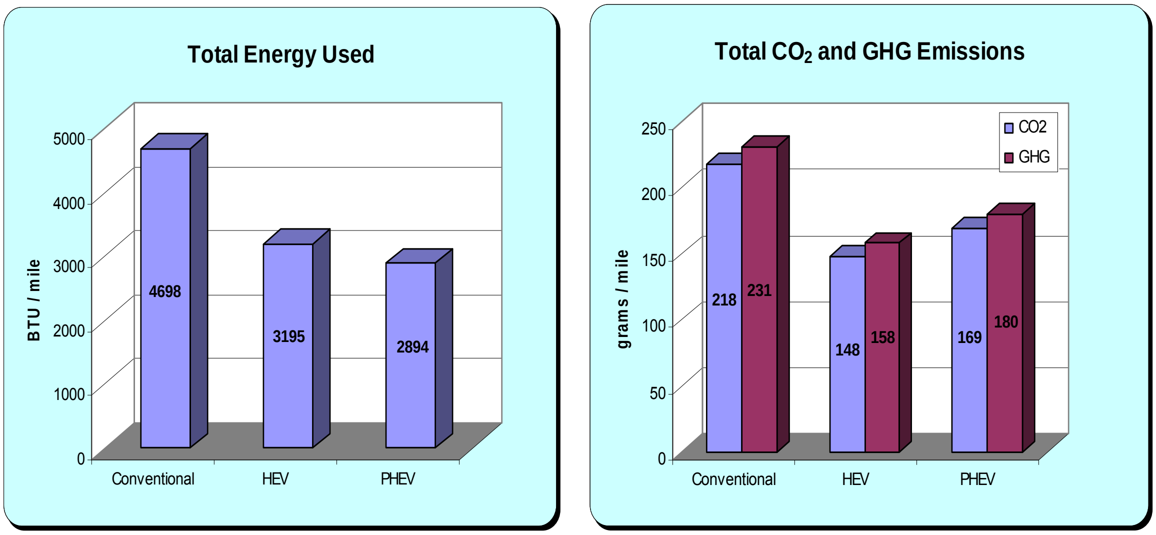

Figure 13: *Basic comparison of total energy used (left) and CO2 and GHG emissions (right) between conventional vehicles, HEVs, and PHEVs in southern California in 2030.*

3.3.3. Increased Renewable Generation

Research has shown that, with V2G infrastructure, PHEVs have the potential to increase the penetration of intermittent renewable energy sources, such as wind and solar. More specifically, PHEVs equipped with V2G capabilities can act as absorbers to store excess energy created from wind turbines and solar during high output times and discharge stored energy when solar or wind generation is low, therefore, providing a "firm" and predictable capacity from which utilities may draw. Since extensive investigation of V2G operations was not included in the Phase 1 "baseline" case study, the amount of increased renewable generation in the generation mix credited to the southern California PHEV fleet was not estimated in Phase 1. However, plans to incorporate V2G operations in subsequent phases are planned, which will include the analysis of this particular value proposition.

3.4. Utility Benefits

The PHEV charging schedule used for this analysis is shown in Figure 14. Most of the charging occurs during the off-peak hours, with just 10% of vehicles plugging in between 5 PM and 6 PM, and staying plugged in for an hour at most. This demand represents 1.66 million PHEVs on the entire California grid.

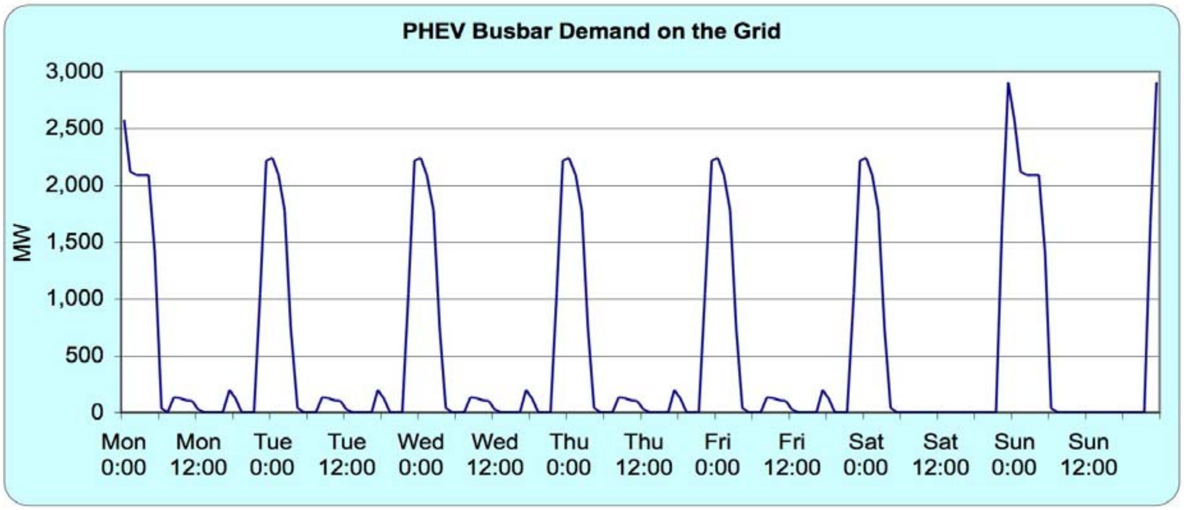

Figure 14: *PHEV charging schedule used in the Phase 1 case study.*

The relatively slow penetration of PHEVs in the market in combination with smart charging that shifts demands to off-peak times leads to very little impact on overall peak demands while providing the utility with additional sales during off-peak times. Figure 15 shows the modeled net electric load for California during the peak week of the year with and without the PHEV load shown above. The extra demand from PHEVs is only noticeable in the valley of the curves; the morning and afternoon impacts (~100 MW) are not at the peak time and not of concern. The benefits to the utility include increased sales from existing capacity, thereby providing the potential to recover more of their fixed costs.

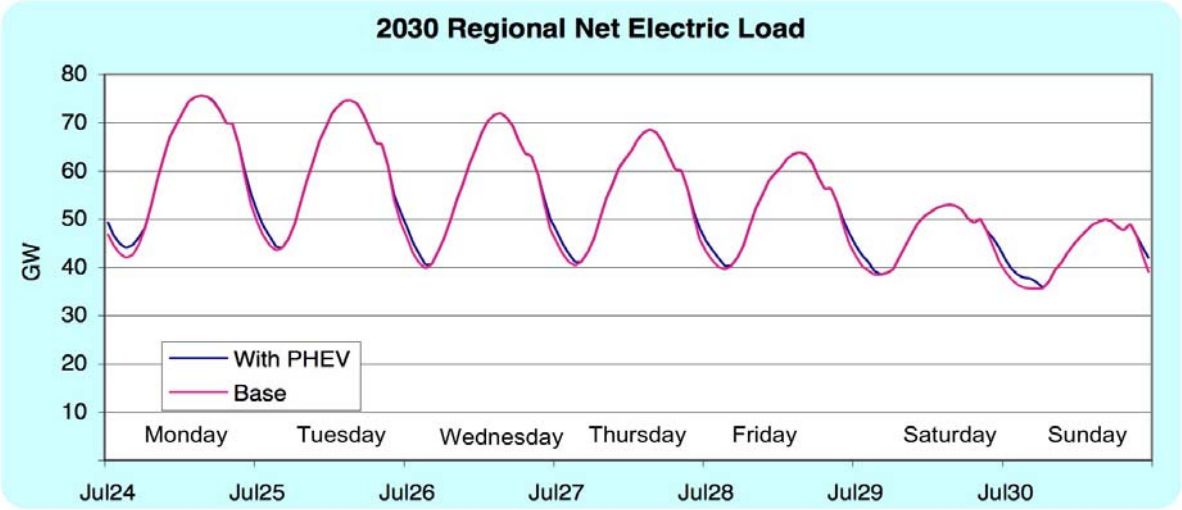

Figure 15: Modeled net electric load for California during peak week of the year with and without PHEV load.

If all PHEV owners choose to charge their vehicles in the evening (5 PM – 6 PM) then peak demands can be affected. Figure 16 shows the impact when all the PHEVs plug in between 5 PM and 6 PM. In the left-hand scenario, 90% of PHEVs still plug in at 110V and only 10% at 220V. In the "worst-case" scenario on the right, all vehicles plug in at the 220V voltage for a "fast" charge, therefore, resulting in a much larger impact on demand. These graphs clearly show the benefit to the utility of providing incentives for customers, such as special off peak rates, to shift their charging habits to nighttime. With that in mind, PHEV owners must be educated on what hours offer the highest financial benefits and understand why charging during peak hours is discouraged by the utilities. Additional details on the utility analysis are in Appendix E.

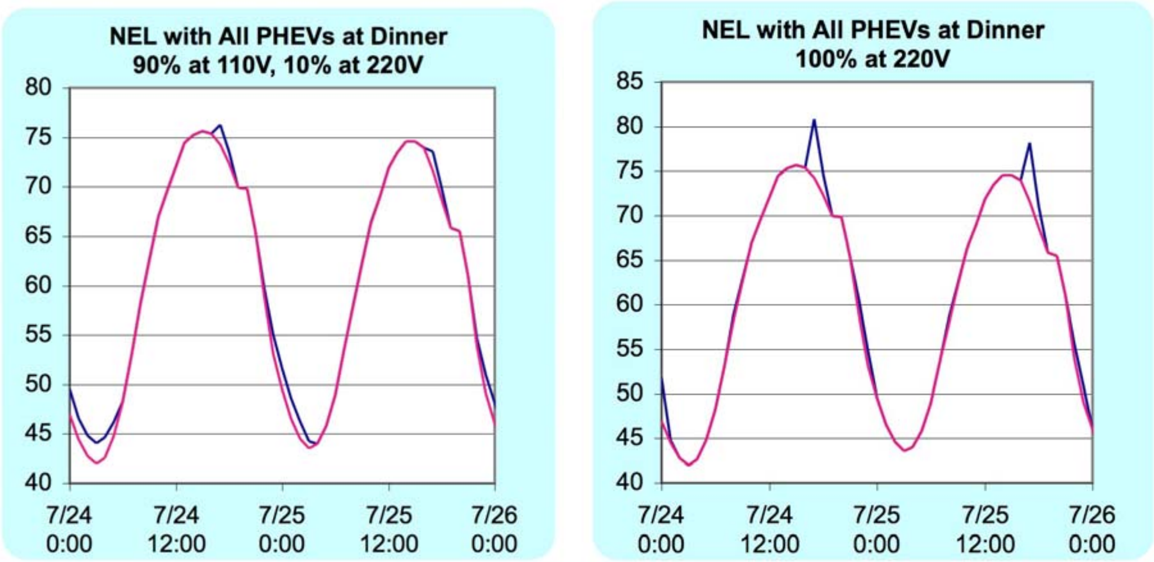

Figure 16: 90% of PHEVs plug in at 110V and 10% of PHEVs plug in at 220V (left), and 100% of PHEVs plug in at 220V resulting in much larger impact (right).

3.5. *Commercial Building Owner Benefits*

A commercial building owner may be able to use some of the employees' vehicles (with the owners' permission) to reduce the building's peak demand and thereby its electric bill. At the same time, the building would also shift some of its electricity purchases from afternoon peak prices to morning mid-peak prices, saving some additional funds. However, the total savings is dependent on the load shape of the facility. Also, the vehicle owners will expect some form of compensation, either monetary rebates or non-monetary incentives (e.g., preferred parking spaces), for wear and tear on the battery. They will also expect to have at least the same SOC when they leave work as they did upon arrival. Also, the net savings to the building will need to be sufficient to justify the capital and ongoing operations cost for the program.

An initial analysis of large commercial building owner savings was conducted using load curves from the California Energy Commission End-Use Survey (CEC 2006). By adjusting the hot, typical, and cold day load curves to reflect the 2006 daily peak loads from the LADWP, the loads that a 20-story, 350,000 square foot office building might see each day could be simulated.

For a large office building with a 1.5 MW peak demand and up to fifty PHEVs available, the building's owners could purchase extra power in the morning to recharge the batteries to full charge. Then in the afternoon, the building could withdraw that power, squaring off each day's peak as shown in Figure 17. In this example, PHEVs began plugging in at 8 AM, charged through the morning, and then released the same amount in the afternoon. This dropped the peak demand roughly 60 kW. Using current SCE and LADWP commercial rates, the savings from both reduced demand charge and lower cost energy purchases was $1000-2000 per month. By 2030, the amount will likely increase, but the amount of savings depends on the building's rate structure.

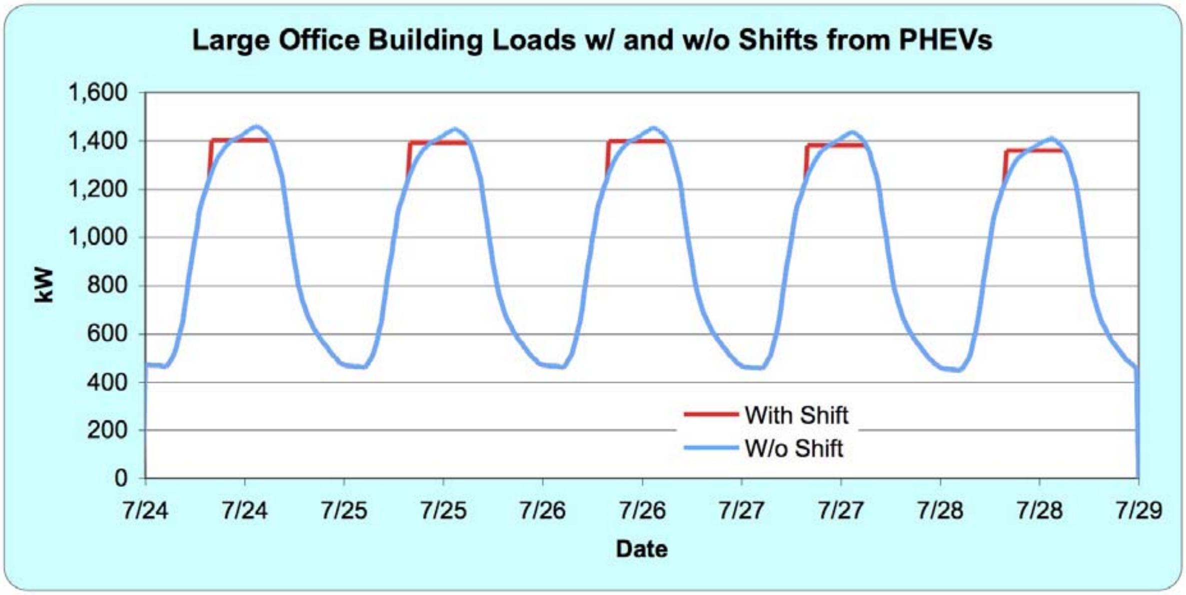

Figure 17: *Outcome of building owners squaring off each day's peak by purchasing extra power in the morning to completely recharge the batteries.*

Most of the savings in these examples were from the demand reduction. If PHEV owners plugged in at 7 AM instead of 8 AM, more vehicles could be fully charged and the peak could be lowered by 80 kW compared to the previously mentioned 60 kW. Further details on commercial building benefits are included in Appendix H.

3.6. *Battery Alternative Design and Ownership Options*

Battery cost may be the single largest impediment to large scale commercialization of PHEVs. Several approaches to reducing this cost for the consumer have been proposed. These include incorporating a less expensive battery with a reduced energy storage system capacity and/or having a third party (someone other than the auto manufacturer or the consumer) own the batteries available for lease to the consumer. Developing a business case around either or both of these scenarios is not a trivial activity.

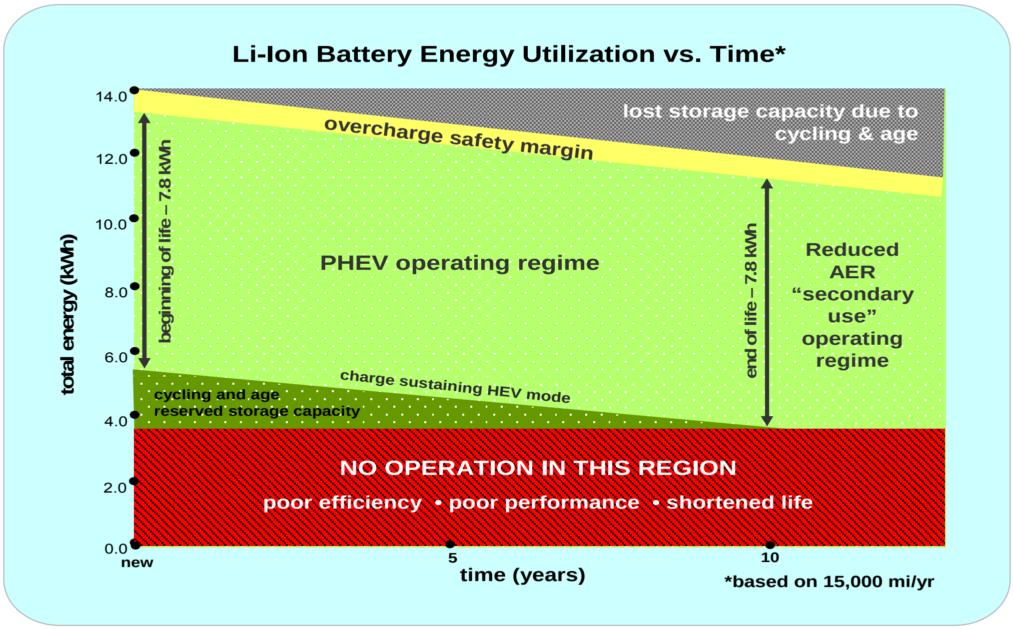

Figure 18: *PHEV-30 energy storage utilization during ten year (150,000 mile/ operation).*

To achieve a ten year (~150,000 mile) life, the batteries have in fact been oversized to avoid certain abuses. For example, the battery must not be overcharged; therefore, a safety margin of 5% capacity is unused in this study and operation above the 95% SOC is avoided. If Li-ion cells are discharged or operated at a level lower than ~25% SOC, their efficiency and performance is degraded, plus significant heating and aging will occur. To avoid this occurrence, a “No operation region” has been established in this study, and the batteries will not be operated below 25% SOC. The net result is an operating regime as shown in Figure 18.

The PHEV in this study required a Li-ion battery pack with a total energy capacity of ~14 kWh although the actual amount of energy needed to provide a 30 miles AER is 7.8 kWh.

As shown in Figure 18, anticipated degradation over a 10 year lifetime[s] led the project team to include an additional 2 kWh, essentially giving the PHEV a 35 mile AER in the initial year of operation. For this study, the AER was constrained to a 30 miles AER throughout its lifetime. The battery pack reaches "end-of-life" at around 10 years when the energy storage system can no longer provide 30 miles AER. Beyond this point, the vehicle will continue to function as a PHEV, but its equivalent AER will be decreased as shown in Figure 18.

Using Figure 18 as a reference, a manufacturer could down size the battery for a 5 year life by reducing the "cycling and age reserved storage capacity" by one half, or approximately 1 kWh. In 2030, this would save the manufacturer $200 and the consumer $400. This represents a savings of 7% on the cost of the battery pack. At 2008 prices, the total cost of the battery pack integrated into the vehicle would be $28,000 for ten year life or $26,000 for five year life. When looking at total vehicle cost, the relative difference becomes even smaller, with the total 2008 PHEV cost being reduced from approximately $47,000 to $45,000, a 2% reduction. It is the opinion of the project team that very few consumers would choose to purchase a vehicle with one half of the life for a savings of only 7% of the battery cost and 2% reduction on the vehicle cost.

Federal regulations governing the rating of the PHEV's effective electrical range and the potential operating costs may require that the battery perform to a certain level, or risk warrantee replacement of the device. This would deter manufacturers from "downsizing" the energy storage element. For this study, the project team has assumed that regulations such as this will be in place and the battery pack will be designed for 30 miles effective electric range for ten years (~150,000 miles). Beyond that point (defined in this study as "end-of-life"), the PHEV will continue functioning; however, its electric range will gradually decrease.

If these regulations are not in place, which they currently are not, a manufacturer might design the vehicle and battery pack to provide 30 miles AER at the beginning of life, but provide no "cycling and age reserved storage capacity" as shown in Figure 19. This conceptual design would reduce the battery pack size by approximately 2 kWh and cost by 14%. Early in the first year of vehicle life, the AER would be 30 miles. This would soon begin to degrade due to battery cycling, and by the end of ten years the usable storage capacity would be reduced from 7.8 kWh to 5.8 kWh and the AER would be reduced to 22 miles. For the consumer, this degradation would be manifested in continually increasing fuel cost and likely dissatisfaction with the vehicle. It is the opinion of the project team that overall marketability of the vehicle would be greater if it were sold as a PHEV-20, realizing approximately the same savings, but assuring 20 miles AER for the life of the vehicle.

Reducing battery size and energy rating to achieve reduced PHEV costs has very little leverage. Battery cycle life testing indicates that present Li-ion technologies appear to be capable of a ten year (~150,000 mile) life, provided that they are neither overcharged nor consistently operated at high temperatures, nor in charge sustaining mode at a very low SOC. This study assumes that improvements to Li-ion technology and application of quality automotive assembly will result in a ten year (~150,000 mile) battery system that will be

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[s] Battery model was based on proprietary cycle life and yearly degradation of several lithium-ion chemistries.

commonplace by the target timeframe of 2020-2030. By providing safety margins this study can be reasonably confident in achieving the desired electrical range performance and desired lifetime of ten years (~150,000 miles). Note that the loss in storage capacity will slightly exceed 0.2 kWh/yr. Giving up these safety margins will result in unpredictable and significantly shortened battery life.

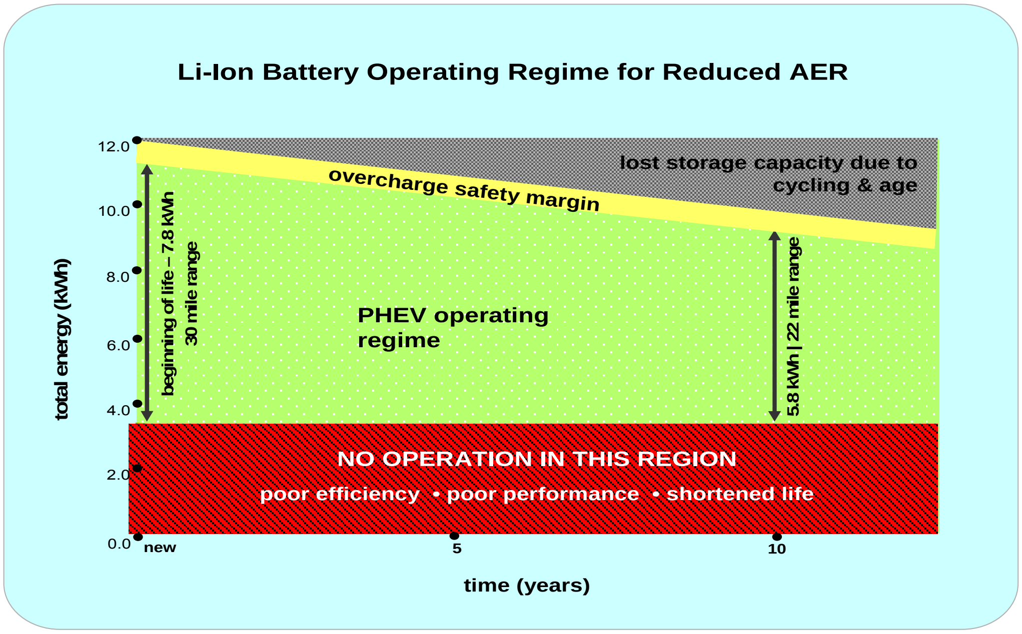

Figure 19: *Potential battery pack conceptual design without reserve capacity to accommodate cycling and aging losses.*

Another alternative for reducing the energy storage cost to the consumer is third party ownership of the batteries. This alternative was explored extensively by one of the breakout groups at the Workshop. Many potential third party owners were identified in the Workshop; however, a business case for these potential owners was not established in Phase 1. As pointed out by one workshop participant, the cost of money is essentially the same across all industries. For an entity to own the batteries and provide a reduced cost to the consumer, an additional value to be gained by that entity must exist. Examples of value propositions that have been offered include the following:

- A business owns the batteries in their employees' PHEVs in exchange for the right to draw electricity from the vehicles to avoid peak demand pricing of electricity. In the summer, 50 PHEVs could save the business approximately $1000-2000/month. Savings accrued over the lifetime of the fleet ($2,500-5,000 per PHEV) would not likely cover the entire cost of the batteries but would cover a significant portion.
- The utility owns or partially offsets the cost of batteries in exchange for the right to discharge the batteries during times of peak demand and recharging the batteries in a controlled manner during off-peak. This scenario has uncertainties in the value of PHEV batteries to the utility versus the cost of permanently installed energy storage units. There are also questions of consumer acceptance and warranty issues regarding the utility's or building owner's charging and discharging the PHEV

batteries. Additional battery life analysis must be performed and consumer surveys should be conducted to determine if this scenario is viable.

- A company that specializes in refurbishing and recycling batteries is also a likely potential owner of PHEV batteries. This company would lease the batteries to the vehicle owner for ten years. At that point in time, the batteries would be removed from the vehicle, refurbished and then leased or sold into a secondary application. To establish a viable business case for this scenario that will result in lower cost to the consumer, this company must receive some additional value due to its ownership of the batteries and that value is not available to others. In the Phase 1 portion of this study, a viable option for that value was not established.

To provide a related industry perspective, a recent study of third party ownership of platinum (Pt) in fuel cell vehicles, performed by Matt Kromer, et al,[9] concluded that, "…such a program offers only marginal benefits to the consumer, and that reducing Pt loading is the top priority." Pt has an advantage over batteries in that its real value has been constant for more than a century. Batteries on the other hand will decrease in value as their energy storage capacity decreases. As stated in Section 3.1.3., the secondary use value of the batteries in this study's PHEV-30 is $1000. In comparison to the original vehicle cost or even the battery cost, this number loses significance.

Additional options for alternative battery ownership options will continue to be explored in future phases by the project team. For example, a data mining company might own the batteries and incorporate a telemetry system to monitor battery performance and SOC. The data mining company could also integrate the battery pack with GPS and collect consumer driving and parking patterns and that information could be marketed. Provided privacy issues are adequately addressed, this is an example of a value that would be uniquely available to the entity owning the batteries.

4. CONCLUSIONS

4.1. Are PHEVs Commercially Viable?

The primary objective of this PHEV Value Proposition Study is to establish potential value propositions that will collectively lead to commercially viable PHEVs, meaning the reduced operating costs attainable with PHEVs must match or outweigh its initial price premium over conventional vehicles or HEVs. Based on the results from the Phase 1 case study set in southern California, the reduced operating costs of a PHEV accrued over its ten year lifetime (~15,000 VMT annually) do indeed result in significant net cost savings over both conventional vehicles and HEVs (Table 7).

Table 7: *Net monetary value of a conventional vehicle, HEV and PHEV-30 accrued over a ten year vehicle lifetime.*

MONETARY VALUE	CONVENTIONAL	HEV	PHEV-30
PURCHASE COSTS	**$21,400**	**$22,600**	**$26,675**
Glider [t]	**$14,400**	**$14,400**	**$14,400**
Powertrain Costs	**$7,000**	**$8,200**	**$12,275**
Engine[c]	$4,250	$2,500	$2,500
Transmission[d]	$2,750	$2,625	$2,625
Motor/Inverter[d]	-	$875	$875
Battery[d]	-	$2,200	$5,600
Charging Plug[c]	-	-	$675
OPERATING COSTS	**$28,325**	**$20,450**	**$15,725**
E30	**$20,625**	**$13,775**	**$4,250**
Electricity	**-**	**-**	**$5,350**
Maintenance	**$6,600**	**$5,925**	**$5,275**
Carbon Tax	**$1,100**	**$750**	**$850**
OWNERSHIP $ BENEFITS	**-**	**-**	**($1,000)**
Battery Recycle Credit	**-**	**-**	**($1,000)**
TOTAL NET COST	**$49,725**	**$43,050**	**$41,400**

Case study results show that liquid fuel and electricity costs for a PHEV-30 are projected to be approximately 6¢ per mile. This compares to a projected conventional vehicle fuel cost of more than twice that, about 13.5¢ per mile and a projected HEV fuel cost of about 1.5 times that, about 9¢ per mile. Over the lifetime of the vehicle, this reduced cost per mile more than outweighs the anticipated ~$5,300 price premium relative to the conventional vehicle. An anticipated recycling credit of approximately $1,000 for an "end-of-life" Li-ion battery pack also increases the PHEV's competitive edge. Furthermore, these savings are prior to

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[t] MSRP of 2009 Toyota Camry SE Base Model (2.4L 4-Cyl.) minus total powertrain costs.

additional value-added propositions, such as benefits to auto OEMs, utilities or government agencies.

The price sensitivity chart in Figure 20 demonstrates the impact of varying retail prices of E30 and electricity used to power the three vehicle types, assuming all other factors are held constant. PHEVs appear to have the lowest overall cost volatility primarily because the effects of price changes can be shared between two fuel types, which is not an option for conventional vehicles or HEVs. Variations in carbon tax rates are also displayed in this chart; all vehicle types are similarly affected by fluctuations in this rate, which result in small changes in operating cost.

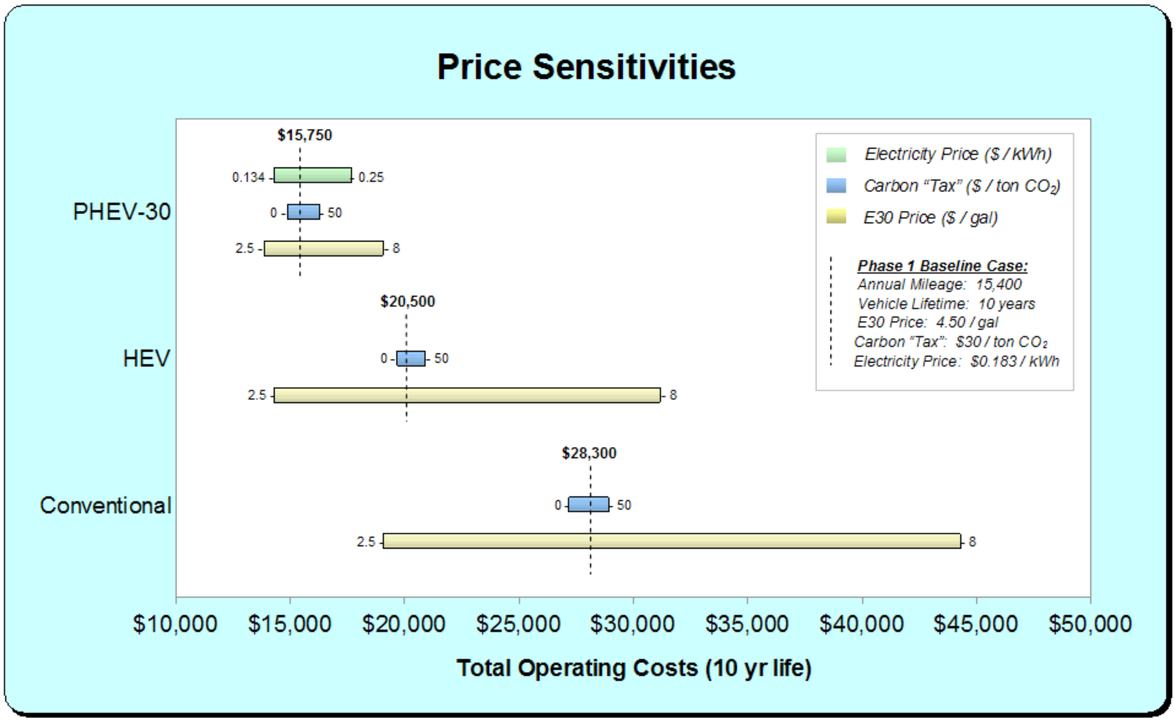

Figure 20: *The impact of varying fuel prices and carbon taxes on each vehicle type's operating cost.*

4.2 Additional Benefits of PHEVs

In addition to monetary benefits, PHEVs are able to dramatically decrease dependence on foreign oil by substituting the majority of it with electricity. Case study results show that, on average, a single PHEV-30 will consume approximately 80% less gasoline than conventional vehicles (~250 less gallons annually) and 70% less gasoline than HEVs (~150 less gallons annually). With 60% of oil imported from foreign lands, the southern California fleet of 1 million PHEVs has the potential to reduce imported oil by approximately 8 million barrels (150 million gallons) annually if the PHEV fleet substituted for conventional vehicles or by approximately 4.5 million barrels (90 million gallons) annually (if the PHEV fleet substituted for HEVs).

PHEVs also demonstrate significant improvements in GHG emissions reductions in some cases. Relative to conventional vehicles, PHEVs reduce both CO_2 emissions and overall GHG emissions by nearly one quarter. PHEVs also use approximately 40% and 10% less total energy compared to conventional vehicles and HEVs, respectively. For this case study, CO_2 and GHG emissions for the PHEV are slightly higher than HEVs, primarily because the source of emissions associated with the electricity used in PHEV is higher than the larger volume of E30 used in HEVs; however, this is extremely dependent on the marginal generation mix.

As demonstrated in "Benefits to Utilities," the relatively slow penetration of PHEVs in the market in combination with smart charging that shifts demands to off-peak times leads to very little impact on overall peak demands while providing the utility with additional sales during off-peak times. The benefits to the utility include increased sales from idle capacity, thereby providing the potential to recover more of their fixed costs. If all PHEV owners choose to charge their vehicles in the evening (5 PM – 6 PM), then peak demands can have a negative affect on the grid. Such affects clearly show the benefit to the utility of providing incentives for customers to shift their charging times to nighttime.

Commercial building owners may also benefit from having their employees plug in at their workplace upon arrival in the morning. By charging the batteries when demands at the building are below peak, commercial building owners can use the power stored in the batteries towards reducing building peak billing demand and thereby the electric bill. At the same time, some of their electricity purchases could be shifted from afternoon peak prices to morning mid-peak prices, saving some additional funds. However, the total savings is dependent on the load shape of the facility. Also, the vehicle owners will expect some form of compensation, either monetary rebates or non-monetary incentives (e.g., preferred parking spaces), for wear and tear on the battery. The net savings to the building will need to be sufficient to justify the capital and ongoing operations cost for the program.

4.3 Action Items Between Now and 2030

To ensure a successful introduction of PHEVs and subsequent thriving market, several pressing issues must be addressed over the course of the next two decades:

- *Increased Federal R&D for Advanced Batteries:* The cost of batteries may be the single largest impediment to large scale commercialization of PHEVs. In order to produce PHEV batteries that meet the required levels of durability, quality and safety at an affordable cost, increased Federal R&D for industry, universities, national laboratories and domestic battery manufacturers is needed.
- *Increased Domestic Battery Manufacturing Capacity:* The U.S. must establish a competitive edge and leadership role in the PHEV battery industry in order to avoid replacing imported oil with imported batteries. To ensure an ample supply of domestically produced batteries that consistently meets or exceeds the demand for PHEV batteries, expansions in domestic manufacturing capacity must take place. Therefore, incentives to make domestic production both appealing and worthwhile to battery manufacturers are necessary.
- *Passage of Supportive Policies and Regulations:* Similar to the introduction of HEVs, policies that offer financial incentives to potential PHEV owners are

useful to significantly boost market penetration. Favorable PHEV policies would include tax credits to PHEV purchasers, converters and utilities. A nationwide RPS and fuel efficiency standard would also contribute to steady growth of the PHEV market.

- *Consumer Education:* To accrue the level of lifetime savings and benefits demonstrated in this study, PHEV owners must be knowledgeable of how to optimally charge their vehicle. Consumer education would be necessary to teach owners to not only fully charge each night but also charge opportunistically (when total daily commutes are expected to exceed 30 miles) to maximize electric range. However, owners must also be aware of the monetary benefits associated with charging during “off-peak” hours as opposed to during the more expensive “peak” hours.
- *Distribution System Improvements:* If concentrated segments of the population own two or more PHEVs and they use a quick-charge at 220V, it is possible that the local distribution system may not be able to support the extra load. Multiple houses served by a single transformer, or an apartment building with a limited size service and transformer, may need to be upgraded to handle the increased load. Smart chargers can alleviate this by monitoring conditions on the local lines as well as system wide power in order to optimize charging schedules of multiple vehicles.
- *Growth toward a Robust Private and Public Charging Infrastructure:* The majority of consumers do not have access to personal garages or carports for charging their vehicle. Therefore, steps should be taken to provide public charging stations in frequented areas throughout most cities, including parking garages, work locations, and shopping areas, to accommodate PHEV charging during the day. Funding for such installations capable of smart metering and time differentiated rates should be sought in preparation for the introduction of PHEVs. A payment infrastructure that enables consumers to purchase electricity at locations other than their homes and to monitor their electricity costs needs to be addressed. Also, since future PHEVs are expected to offer 220V quick charging capabilities (in addition to 110V or exclusively), potential PHEV owners should be aware that installation of a 220V outlet may be necessary. Reinforcements to overloaded distribution may also contribute to needed infrastructure growth.
- *Collaboration among Major Industry Leaders*: The synergy produced by linking vehicles to the grid creates a novel opportunity for auto manufacturers and utilities that has heretofore never been considered. Both entities have a mutual goal of designing PHEVs that exhibit optimal interaction with the grid, ultimately resulting in added value to their joint costumers.
- *Collaboration with the Education System*: While today’s car is a modern marvel of mechanical engineering, tomorrow’s car will also be a modern marvel of electrical engineering. Ideally, a sustainable high-volume PHEV market will be one that is seamlessly integrated with the grid. Accordingly, the auto industry must undertake an ambitious effort to transition toward the manufacturing, sales, and servicing of electronically-powered products, and the utilities face a similar challenge with PHEVs. While the transition from HEVs to PHEVs will provide

the auto industry with a substantive learning experience, the educational system can accelerate the transition by training electrical engineers and technicians skilled in servicing batteries and electrical systems. The education system will also need to address the need for increased environmental and energy awareness of the public, who will be the customers driving the demand for PHEVs and also interacting with the grid. It is essential that consumers are educated on the long term PHEV benefits and how is the best way to maximize these benefits.

4.4 Phase 1 Lessons Learned

The Phase 1 case study presented the project team with the challenge of integrating most aspects of the PHEV industry in order to provide an all-encompassing outlook. As a result, many potential refinements were noted throughout the process that we believe will result in more accurate outputs if re-runs of the case study were to be performed in the future. For example, EIA projections were used as guidelines for anticipated generation mixes by geography. While these values may be appropriate for evaluating the entire state of California, the project team believes that long term projections constructed by actual utilities within the specific southern California region (e.g., SCE) would provide more accurate outlooks for the 2030 timeframe. Using actual time-differentiated electricity rates from area utilities would also increase the accuracy of operating costs associated with specific charging styles. Consumer-based representative drive cycle data collected from the southern California region would also be incorporated in future revisions of this Phase 1 case study.

A more accurate recycling credit for batteries may also be obtained if ample time was taken to update the SNL / Sentech, Inc. report[f] on secondary applications for such batteries to account for technology improvements and economies of scale of arriving battery technologies (e.g., Li-ion). A study that accurately compares the advantages and disadvantages of 110V and 220V charging would also be very valuable when drawing assumptions of the 2030 PHEV fleet.

5. RECOMMENDATIONS FOR FUTURE PHASES

Since southern California likely displays the most favorable scenario for the introduction of PHEVs, future case studies will investigate alternative geographic settings to account for the nation's diverse range of generation mixes, climates and other variables. Possible candidates for future locations include the primarily coal-fired generation mix of the Tennessee Valley and the highly diversified mix of the colder Northeast region. A scenario that represents a location with a high nuclear generation mix may also be analyzed to quantify potential benefits resulting from significantly reduced CO_2 emissions.

An extensive sensitivity analysis is also planned for future phases in order to provide a more comprehensive market outlook. Vehicle platforms will be expanded to incorporate PHEV-15s and possibly series powertrains, and additional sensitivities include variance in battery cost, electricity pricing options, and weather extremes (e.g., a dry year may limit the contribution of hydro to the generation mix). Increased variability in consumer driving habits may also be investigated using multiple "driver types." Future phases will also weigh the initial cost premium of purchasing a PHEV (likely paid for with a monthly lease) against the increased monthly operating costs associated with conventional vehicles and HEVs. A quantitative risk analysis has also been planned for future phases. The impact of potential incentives required to successfully introduce PHEVs into the marketplace and encourage battery manufacturers to increase capacity domestically will also be researched in Phase 2's Market Introduction Study.

In future phases, an evolution of the current "battery aging" model has been proposed that is directly linked to the duty cycles in order to permit battery life estimation under various conditions. This model will be based on a more detailed analysis of battery duty cycles (e.g., history of SOC, depth of discharge (DOD), C-rates, temperatures) under different scenarios and driving needs. Analyzing the tradeoff between a shorter battery life and higher C-rates is of particular interest in future phases. All models will be based on experimental data related to battery usage for PHEV applications, and these activities will be strongly connected to the OSU-CAR PHEV and Battery Research programs. The project team will make use of battery pack and duty cycle data acquired from two prototype PHEVs (ChallengeX and Prius Hymotion conversions) and from cell and module data acquired in the OSU-CAR battery aging lab. Outputs will include battery life estimation as a function of vehicle specifications, driving habits, battery sizing and control as well as PHEV requirements and battery charging strategies to support grid-PHEV interface.

Modifications to value propositions analyzed in Phase 1 will be made based on testing results and review by DOE and the Guidance and Evaluation Committee. Specifically, updated utility, industry and national laboratory data related to consumer preference surveys, T&D system characteristics, etc. will be incorporated in future analysis. Case study results will be refined using actual SCE and LADWP rate structures and NREL drive cycle data. In addition, the project team intends to include the following value propositions to the existing "baseline" model of Phase 1:

- Ancillary services for V2G operation. This may include spinning reserves, regulating reserves, and volt/var support. The final list of ancillary services, their value and requirements, and the amount of each that PHEVs could provide, will be determined by reviewing CAISO requirements, generation dispatch history, historical ancillary services market data, and EPRI's previous ancillary services study for SCE.

- Enhanced responsive load, either regulating the charge for an aggregation of PHEVs (e.g., in a parking garage) with 110V unidirectional capability only, or controlling individual charge and discharge of 220V V2G-capable vehicles. Currently, a parking facility serving as an aggregator can only charge for parking "time;" it cannot price battery charging, as that would make it an energy reseller and, therefore, a utility under California law. However, state regulatory changes have the potential to modify this if it is believed to result in the increased adoption of PHEVs. Otherwise, a business model where PHEVs receive reduced rate parking is acceptable.
- Increased utilization of renewable energy generated on-site through enhanced V2B capability. The value stream for this is through the California Solar Initiative (CSI).
- Improved GHG emissions data as a function of generation mix.
- Continued exploration of battery leasing, third party ownership, and buy-back/recycling business models, based on the financial and battery modeling outputs of Phase 1.

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APPENDICES

APPENDIX A. Vehicle Assumptions

Table A - 1: *2030 Vehicle Parameter Assumptions*

	CONVENTIONAL	HEV	PHEV-30
Mass			
Glider Mass (kg)[u]	693	693	693
Engine/Transmission/Final Drive/Wheels (kg)	441	374	374
Power Electronics and Electric Machine (kg)	0	44	44
Energy Storage (kg)	0	50	124
Fuel Subsystem (kg)	58	48	48
Total Vehicle Mass (kg)	1192	1209	1283
Total Vehicle Mass w/ 136 kg Cargo (approx. two passengers)	1328	1345	1419
Parasitic Load			
Frontal Area (m^2)	2.27	2.27	2.27
Drag Coefficient	0.24	0.24	0.24
Electrical Accessory Load (W)	260	260	260
A/C Load (W)[v]	1088	1088	1088
Engine			
Engine Power (kW)	110	50	50
Engine Specific Power (W/kg)	920	920	920
Engine Peak Efficiency (%)	38.5	38.5	38.5
Battery			
Battery Chemistry	-	Li-ion	Li-ion
Battery Energy (kWh)[w]	-	-	14
Battery Power (kW) @ 95% SOC	-	73	-
Battery Voltage (V)	-	260	260
Battery Capacity (A*hr)	-	8	45.9
Battery Rated Life	-	100%, ± 1C (4000 cycles)	100%, ± 1C (4000 cycles)
Battery Total Lifetime (yr)	-	10	10
PE&EM			
Motor Power (kW)	-	55	55
Motor Specific Power (kW/kg)	-	1.4	1.4
Power Electronic Specific Power (kW/kg)	-	12	12
Electric Drive Peak Efficiency (%)	-	92	92
Vehicle Ownership			
1st Length of Ownership	10	10	10
Annual Miles Driven	15,427	15,427	15,427

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[u] Glider mass = Vehicle– (Engine+Motor+Batteries+Transmission+Final Drive+Fuel Storage+Wheel) Based on 30% reduction in current glider mass as per DOE GPRA Study Results. Original glider mass is 990 kg.

[v] Data provided by John Rugh (NREL) - assumed 50% of the time when the A/C is on, the vehicle is undergoing a cooldown from a solar soak when the initial interior air and mass is 60-80°C. The other 50% is steady state operation. 65% humidity during ARCRP tests.

[w] Only approximately 8 kWh of the 14 kWh storage is considered usable capacity in this study's battery model.

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APPENDIX B. Vehicle Purchase Costs

As seen in Table B-1, a 2009 Toyota Camry SE Base Model (2.4L 4-Cyl.) was used to attain an MSRP of a standard mid-size sedan. Powertrain component cost equations were gathered from two primary sources: the DOE FCVT Multi-Year Program Plan (2008) and EPRI's 2001 report titled "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options." All powertrain components received a 100% retail markup. The total powertrain cost was then subtracted from the MSRP to estimate the cost of the glider.

Table B - 1: *2030 vehicle cost calculation basis.*

	CONVENTIONAL	HEV	PHEV-30
BASIS FOR 2030 COST CALCULATIONS			
MSRP	$21,390	-	-
Glider	Conventional MSRP – Conventional Powertrain		
Powertrain[x]	Engine + Transmission + Motor/Inverter* + Battery* + Charging Plug*		
Engine	$14.5 * kW + 531		
Transmission	$12.5/ kW		
Motor/Inverter	-	$8/kW	
Battery	-	$20/kW	$200/kWh
Charging Plug	-	-	$380 + Baseline Inverter

* - If applicable

Table B - 2: *2030 vehicle purchase costs (2008 $)*

2030	CONVENTIONAL	HEV	PHEV-30
PURCHASE COSTS	**$21,390**	**$22,605**	**$26,668**
Glider	**$14,388**	**$14,388**	**$14,388**
Powertrain Costs, including:[17]	**$7,002**	**$8,217**	**$12,280**
Engine	$4,252	$2,512	$2,512
Transmission	$2,750	$2,625	$2,625
Motor/Inverter	-	$880	$880
Battery	-	$2,200	$5,600
Charging Plug	-	-	$663

To demonstrate the anticipated cost reductions between now and 2030, today's purchase cost of all three vehicles are provided in Table B-3. For purposes of this study, the cost of a 2030 conventional vehicle has been held constant to demonstrate individual component cost reductions expected in HEVs and PHEVs. However, an incremental cost for all 2030 vehicles is likely to accommodate a 30% reduction in vehicle weight and fuel efficiency of

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[x] All powertrain components and charging plug exhibit a retail markup of 100%.

35 mpg. With that said, the transmission and engine components are believed to be near maturity, so no relative cost reductions are expected from these components in future years. Electric powertrain components (e.g., motor/inverter, battery), on the other hand, are expected to decrease in cost significantly over the next two decades.

***Table B - 3**: Vehicle purchase costs if purchased in today.*

2008	CONVENTIONAL	HEV	PHEV-30
PURCHASE COSTS	**$21,390**	**$26,235**	**$52,698**
Glider	**$14,388**	**$14,388**	**$14,388**
Powertrain Costs, including:	**$7,002**	**$11,847**	**$38,310**
Engine	$4,252	$2,512	$2,512
Transmission	$2,750	$2,625	$2,625
Motor/Inverter		$4,510	$4,510
Battery		$2,200	$28,000
Charging Plug			$663

APPENDIX C. Vehicle Operating Costs

Table C - 1: *Vehicle operating costs over a ten year lifetime.*

	CONVENTIONAL	HEV	PHEV-30
OPERATING COSTS	**$28,325**	**$20,456**	**$15,739**
E30*	$20,618	$13,774	$4,254
Electricity*	-	-	$5,339
Maintenance	$6,595	$5,927	$5,283
Battery Replacement	-	$0	$0
Carbon Tax	$1,113	$756	$863

Table C - 2: *Vehicle operating costs over a ten year lifetime (with no vehicle weight reduction and using E10 average blend).*

	CONVENTIONAL	HEV	PHEV-30
OPERATING COSTS	**$30,321**	**$21,764**	**$17,198**
E30*	$23,336	$15,743	$6,526
Electricity*	-	-	$5,217
Maintenance	$6,595	$5,927	$5,283
Battery Replacement	-	$0	$0
Carbon Tax	$1,659	$1,134	$1083

***PHEV drivers are assumed to plug in every night, 5% of post-morning commutes and 15% of post-evening commutes.*

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APPENDIX D. Fuel and Petroleum Imports Savings

Using PSAT, a combination of drive cycles was simulated for each vehicle type to determine how much liquid fuel and/or electricity was consumed. The drive cycles were based on commonly accepted standardized drive schedules. The cycles were combined to reflect common driving habits, average commute time, and annual distance traveled for the southern California region.

Analyzed Drive Cycles:

- ***Trip 1*:** UDDS+US06; daily, 5 days/wk, 48 wks/yr; represents commute to or from work. Assumes 100% SOC when leaving for work (all cases) or heading home from work (5% of cases).
- ***Trip 1b*:** UDDS+US06; twice/day, 5 days/wk, 48 wks/yr; represents commute from work back home when no charging has occurred while at work (95% of cases); initial SOC = final SOC of Trip 1.
- ***Trip 4*:** UDDS; 3 days/wk, 48 wks/yr; represents separate trip after work. Assumes a 1 hr dinner charge, 6-7 pm, that will reach 100% SOC after Trip 1 recharging at 220V)
- ***Trip 4b*:** UDDS; 3 days/wk, 48 wks/yr; represents separate trip after work. Assumes no charge after work commute (initial SOC = final SOC of Trip 1b);
- ***Trip7*:** UDDS+HWFET+HWFET+HWFET+HWFET+UDDS; 124 days/yr;

Table D - 1: *2030 PSAT simulation results for conventional vehicle.*

E30 - 2030	CONVENTIONAL		
	Trip 1	Trip 4	Trip 7
Battery Size (A*hr)	-	-	-
Initial SOC (%)	-	-	-
Final SOC (%)	-	-	-
Elec. Consumption (Wh)	-	-	-
Fuel Economy (mpg)	28.54	29.99	41.81
F.E. gas equiv. (mpg)	30.62	32.17	44.85
Fuel Mass used (kg)	1.52	0.70	3.77
Fuel Volume (gal)	0.54	0.25	1.33
% EV	0.00	0.00	0.00

Table D - 2: *2030 PSAT simulation results for HEV.*

E30 - 2030	HEV		
	Trip 1	Trip 4	Trip 7
Battery Size (A*hr)	7.00		
Initial SOC (%)	59.98	60.31	58.49
Final SOC (%)	59.98	60.34	58.49
Elec. Consumption (Wh)	Charge Balanced		
Fuel Economy (mpg)	43.77	52.50	58.33
F.E. gas equiv. (mpg)	46.96	56.33	62.58
Fuel Mass used (kg)	0.99	0.40	2.70

Fuel Volume (gal)	0.35	0.14	0.95
% EV	25.64	49.00	21.01

Table D - 3: *2030 PSAT simulation results for PHEV-30.*

E30 - 2030	PHEV-30				
	Trip 1	Trip 1b	Trip 4	Trip 4b	Trip 7
Battery Size (A*hr)	45 (mass of 52.6)				
Initial SOC (%)	95.00	58.61	95.00	29.48	95.00
Final SOC (%)	58.61	29.48	80.41	29.57	29.57
Elec. Consumption (Wh)	4,492.91	3,384.78	1,839.38	-10.55	7,864.17
Fuel Economy (mpg)	815.79	148.48	∞	46.64	148.31
F.E. gas equiv. (mpg)	841.89	153.23	∞	48.13	153.05
Fuel Mass used (kg)	0.06	0.28	0.00	0.45	1.08
Fuel Volume (gal)	0.02	0.10	0.00	0.16	0.38
% EV	94.92	81.05	100.00	54.57	71.53

Table D - 4: *Fuel consumption for each 2030 vehicle type.*

	Total Fuel Volume Used (gal)		
Trip	**Conventional**	**HEV**	**PHEV-30**
1	257.80	167.73	27.84
4	35.39	20.26	19.58
7	164.98	118.10	47.12
Total Volume E30 (gal) - Annual	**458.18**	**306.09**	**94.54**
Total Volume E30 (gal) – Lifetime	4,581.8	3,060.89	945.44
Total E30 Cost - Lifetime	$20,618.09	$13,744.00	$4,254.48
Total brls gasoline - Annual	16.60	11.09	3.43
Total brls gasoline (imported) – Annual	9.96	6.65	2.06
Differential from CV per yr	-	5.51	13.18
Differential from HEV per yr	-	-	7.66
Annual southern Cal Fleet Gasoline Savings (brl) – (relative to CV)	-	-	13,175,208
Annual Southern Cal Fleet Gasoline Savings (brl) – (relative to HEV)	-	-	7,664,670
Annual Southern Cal Fleet Imported Gasoline Savings (brl) - (relative to CV)	-	-	7,905,125
Southern Cal Fleet Imported Gasoline Savings (brl) - (relative to HEV)	-	-	4,598,802

Table D - 5: *Total electricity consumption for each 2030 vehicle type.*

	Total Electricity Used (kWh)		
Trip	**Conventional**	**HEV**	**PHEV-30**
1	-	-	1,903.94
4	-	-	38.44

7	-	-	975.16
Total – Annual (kWh)	-	-	2,917.54
Total – lifetime (kWh)	-	-	29,175.40
Electricity Cost - Annual	-	-	$533.91
Electricity Cost - Lifetime	-	-	$5,339.10

Table D - 6: *PSAT simulation results for conventional vehicle with no weight reduction and using E10.*

E10, No weight reduction	**CONVENTIONAL**		
	Trip 1	Trip 4	Trip 7
Battery Size (A*hr)	-	-	-
Initial SOC (%)	-	-	-
Final SOC (%)	-	-	-
Elec. Consumption (Wh)	-	-	-
Fuel Economy (mpg)	26.73	24.94	34.78
F.E. gas equiv. (mpg)	27.59	25.74	35.89
Fuel Mass used (kg)	1.64	0.85	4.56
Fuel Volume (gal)	0.58	0.30	1.61
% EV	0.00	0.00	0.00

Table D - 7: *PSAT simulation results for HEV with no weight reduction and using E10.*

E10, No weight reduction	**HEV**		
	Trip 1	Trip 4	Trip 7
Battery Size (A*hr)	7.00		
Initial SOC (%)	55.51	60.17	60.17
Final SOC (%)	55.51	60.17	60.17
Elec. Consumption (Wh)	Charge Balanced		
Fuel Economy (mpg)	37.38	44.97	53.99
F.E. gas equiv. (mpg)	38.58	46.41	55.72
Fuel Mass used (kg)	1.17	0.47	2.93
Fuel Volume (gal)	0.41	0.16	1.03
% EV	33.15	42.50	21.81

Table D - 8: *PSAT simulation results for PHEV-30 with no weight reduction and using E10.*

E10, No weight reduction	**PHEV-30**				
	Trip 1	Trip 1b	Trip 4	Trip 4b	Trip 7
Battery Size (A*hr)	45 (mass of 52.6)				
Initial SOC (%)	95.00	52.75	95.00	29.34	95.00
Final SOC (%)	52.75	29.34	78.04	29.86	29.86
Elec. Consumption (Wh)	5,033.56	2,633.92	2,074.85	-57.16	7,613.12
Fuel Economy (mpg)	346.65	71.14	∞	41.64	110.55
F.E. gas equiv. (mpg)	357.74	73.42	∞	42.97	114.09
Fuel Mass used (kg)	0.13	0.61	0.00	0.51	1.43

Fuel Volume (gal)	0.04	0.22	0.00	0.18	0.51
% EV	90.00	71.22	100.00	48.72	62.54

Table D - 9: *Total fuel consumption for each vehicle (assuming no weight reduction and using E10)*

	Total Fuel Volume Used (gal)		
Trip	**Conventional**	**HEV**	**PHEV-30**
1	276.67	197.86	60.59
4	42.84	23.76	21.81
7	199.06	128.22	62.62
Total Volume E30 (gal) - Annual	**518.58**	**349.84**	**145.02**
Total Volume E30 (gal) – Lifetime	5,185.76	3,498.39	1,450.21
Total E30 Cost - Lifetime	$23,335.93	$15,742.74	$6,525.93
Total brls gasoline - Annual	18.79	12.68	5.25
Total brls gasoline (imported) – Annual	11.27	7.61	3.15
Differential from CV per yr	-	6.11	13.53
Differential from HEV per yr	-	-	7.42
Annual southern Cal Fleet Gasoline Savings (brl) – (relative to CV)	-	-	13,534,622
Annual Southern Cal Fleet Gasoline Savings (brl) – (relative to HEV)	-	-	7,420,944
Annual Southern Cal Fleet Imported Gasoline Savings (brl) - (relative to CV)	-	-	8,120,773
Southern Cal Fleet Imported Gasoline Savings (brl) - (relative to HEV)	-	-	4,452,566

Table D - 10: *Total electricity consumption for each vehicle (assuming no weight reduction and using E10).*

	Total Electricity Used (kWh)		
Trip	**Conventional**	**HEV**	**PHEV-30**
1	-	-	1,868.99
4	-	-	37.82
7	-	-	944.03
Total – Annual (kWh)	-	-	2,850.84
Total –Lifetime (kWh)	-	-	28,508.38
Electricity Cost - Annual	-	-	$521.70
Electricity Cost - Lifetime	-	-	$5,217.04

APPENDIX E. Electric Generation Analysis using ORCED

The key characteristic of PHEVs is that they recharge from the electricity grid to substitute/supplement gasoline use. Because electricity is generated at the time of use, the timing when vehicles recharge can greatly affect what equipment will be used for the generation. Furthermore, any given region will have a different mix of generation technologies and other demands on the grid, and these must all be taken into account when determining the impact of PHEVs.

For this analysis, the ORCED model (Hadley 2008) was used.[10] The model has been used for over a decade on a wide variety of generation studies. The most recent work was a study of the impact of PHEVs on all thirteen regions of the country (Hadley and Tsvetkova 2008).[11]

Fur topics need to be examined to complete an analysis of PHEVs on the market. First, the supply of electric capacity must be defined. This includes the types of plants, efficiencies, outage rates, operating costs, fuel costs, and emissions. Second, the base demand without PHEVs must be determined. This requires hourly demands for the region, along with the net change in generation requirements due to imports or exports. Third, the total demand from PHEVs is required. This involves finding the size of the market, the plug-in times for the vehicles, the capacity of the batteries, and consequent length of time the vehicles are drawing power from the grid. Last, supply and demand must be matched against each other and the consequent market impacts calculated. At least two scenarios must be run, with and without the PHEVs, to determine the added effect from the vehicles.

Supply

The grid analysis covers the entire California market rather than just southern California. In California, the electric grid is operated as a whole, with the CAISO creating a statewide market for electricity. Some municipal utilities are outside of the CAISO market, but still purchase and sell into that market. Data is available for the regional market, but generally not for individual utilities. The EIA National Energy Modeling System (NEMS) model calculates the power production and sales for the entire California region through 2030. The list of power plants owned by California utilities was determined from NEMS input file for AEO2008.[12] The "unplanned" capacity that the model calculated was added as needed in their Reference scenario. The list of plants includes not only those plants within the borders but also plants owned by California utilities but outside of region, such as portions of the Palo Verde nuclear plant and the Intermountain Power project in Utah. The resulting total capacity by technology roughly matched the capacity defined in the Reference scenario (Table E-1).

Table E - 1: *California generating capacity for 2030*

	AEO2008	ORCED
Coal	4.3	4.1
Oil and Natural Gas Steam	15.6	15.5
Combined Cycle	24.0	23.9
Combustion Turbine/Diesel	10.1	10.0
Nuclear Power	5.5	5.5
Pumped Storage	3.7	3.7
Renewable Sources	20.1	19.8
Distributed Generation	2.6	2.6
Total Capacity	85.9	85.2

The AEO2008 also projects fuel prices for each region through 2030. The EIA's reference case has what some would think of as relatively low future fuel prices. Figure E-1 below shows the prices per mmBtu for each major fuel in the California region. Natural gas stays between $6 and $8/mmBtu through 2030, although current prices (and the most recent forecast in the Short-Term Energy Outlook from EIA) are $11/mmBtu. This study doubled the AEO2008 fuel prices for 2030 as the reference prices, but sensitivities were performed using the AEO2008 prices and a quadrupling of those prices.

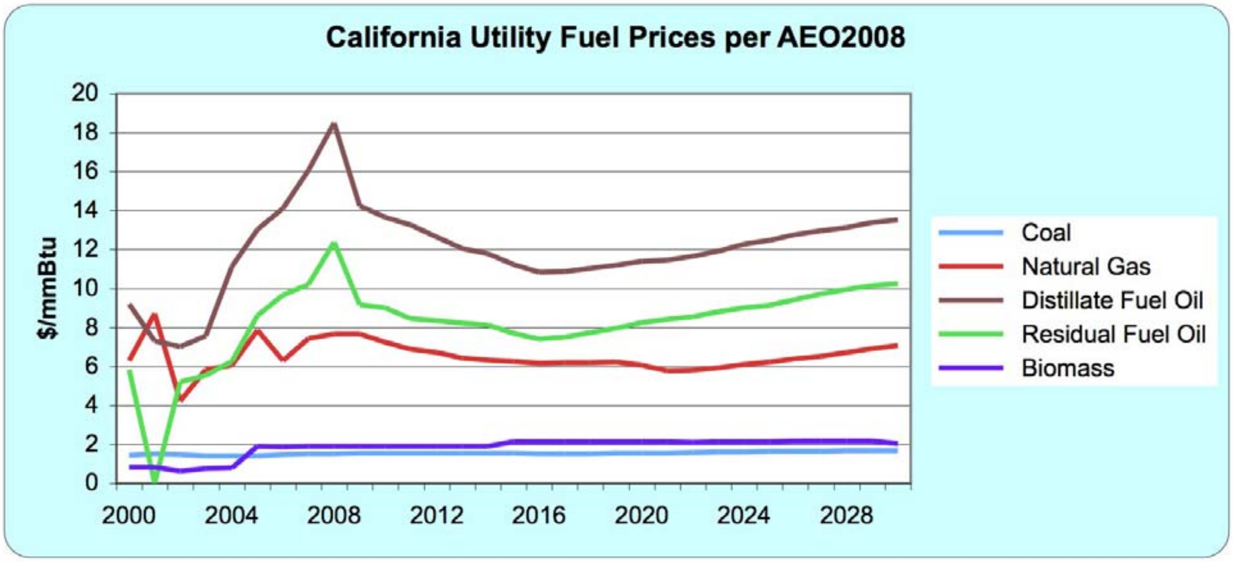

Figure E - 1: *AEO2008 reference scenario California utility fuel costs.*

The 1480 power plant units from the AEO2008 data sets were aggregated by technology, fuel, and variable cost, into 199 plant groups (Figure E-2). The hydroelectric and pumped storage capacity is off the scale at 9,700 MW and 3,400 MW respectively. The hydro capacity was split such that 2,000 MW was treated as baseload and 7,700 MW was used to supply peak demands. Sensitivities were run to understand the impact on the marginal production. Higher hydro baseload power reduced the amount of natural gas on the margin during the low demand periods, making coal the marginal fuel slightly more of the time.

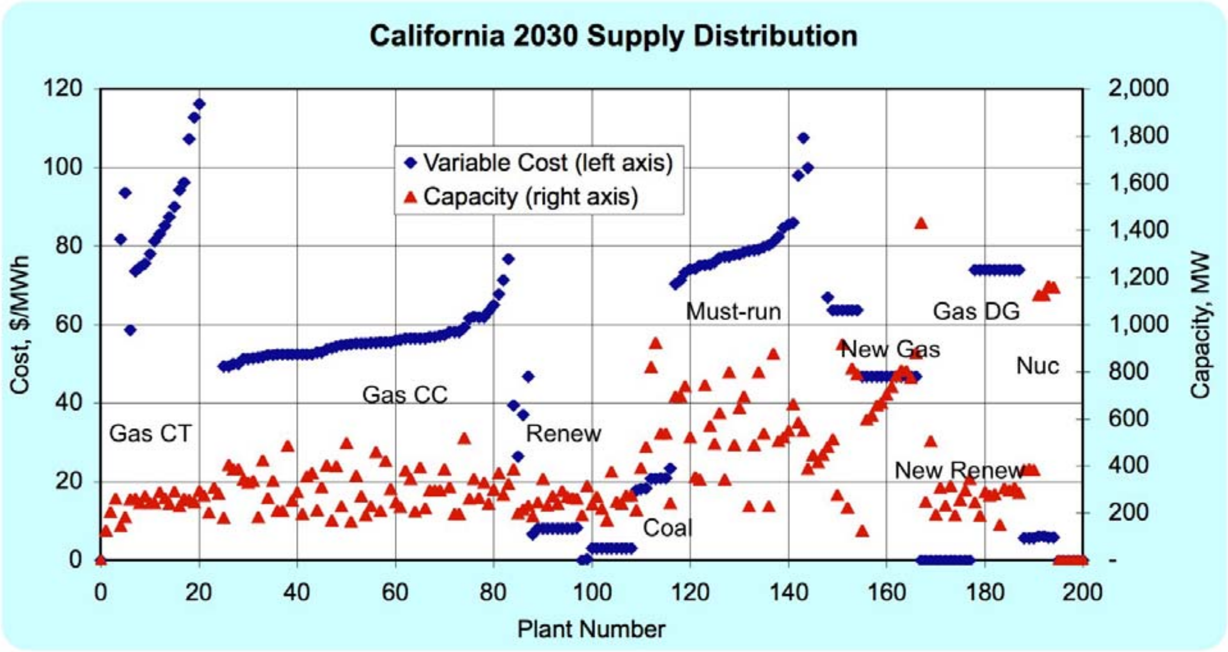

Figure E - 2: *California power plant groups.*

Generation capacity factors are a function of each plant group's relative variable cost, forced outage rate, planned outage rate, and the overall dispatch of the system's plants to the system's demands. After developing the reference supply and demand amounts, and dispatching them in the model, the resulting generation, capacity factors, and percent of total were compared to the AEO2008 reference scenario. Some of the renewable technologies had their capacity factors raised slightly so that the ORCED results (with AEO2008 fuel prices) would approximate those from the AEO2008 Reference case (Table E-2).

Table E - 2: *California 2030 generation and capacity factors from Reference AEO2008 and ORCED scenario.*

	Generation		Capacity Factor		Percent of Total Gen	
	NEMS	ORCED	NEMS	ORCED	NEMS	ORCED
Coal	32.4	29.7	86%	82%	13%	12%
Petroleum	0.1	0.0			0%	0%
Natural Gas	96.1	99.6	22%	23%	38%	39%
Nuclear	43.1	42.0	90%	88%	17%	17%
Renewable Sources	83.7	81.4	48%	47%	33%	32%
Total Generation	255.5	252.7	35%		101%	100%
Sales to Customers	252.8				100%	0%
Generation for Own Use	2.7				1%	0%
Distributed Generation	0.5	0.1			0%	0%

The ORCED run had somewhat less coal and more gas generation, and the capacity factors for renewable technologies (including hydro) were slightly less. The geothermal and new wind plants' capacity factors were raised above what the original NEMS inputs used so that the total renewable capacity factor would approach the AEO2008. One source of difference is that NEMS calculates generation for internal use, while ORCED does not.

Base Demand

Electricity demands in ORCED are modeled as load duration curves (LDCs) for three seasons of the year: summer, winter, and offpeak. To create the LDCs, the hourly loads for the region must be defined. This is also necessary to match PHEV charging profiles to the system demands at the same time.

For this analysis, the hourly loads for the CAISO and for LADWP from 2006 were combined. The sum of these loads represents the net electrical load for these two regions. The two entities combined sum to roughly the amount of net energy for load that the AEO2008 shows for California in 2006, but must be trued up to that amount and escalated to the 2030 value. Each hour's MW values were multiplied by 1.271 to represent the growth to 2030. Figure E-3 below shows the hourly loads over the year.

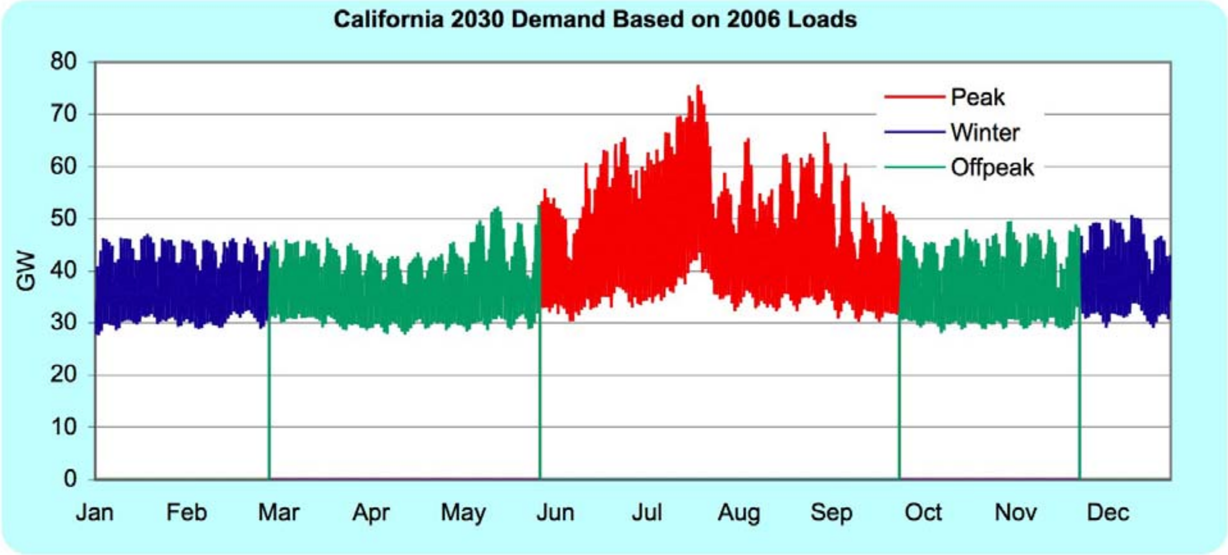

Figure E - 3: *California hourly demands for 2030 based on escalating 2006 loads.*

NEMS allows imports and exports between the various regions of the country based on available transmission capacity and internal calculations on relative cost of power. ORCED does not model the other regions in order to determine economic transfers in or out. They would be a function of the relative demands and supply in each region at any point in time. Instead ORCED increases the base demand amounts to represent the exports or lowers them to represent the imports. The remainder represents the loads that are met by the plants within the region. The hourly loads are converted into load duration curves by calculating histograms for each season.

NEMS outputs show net generation amounts for each region as well as customer net demands for the entire year, but it does not provide information on when the imports or exports occurred. To simulate the net imports into ORCED, the total imports were divided between the three seasons based on their relative demands. Then that amount of import was applied to each hour based on the load in that hour as compared to the average load for the season. Rather than a constant amount of import each hour, it was assumed that at peak demand, imports would only be half of the amount at the average demand. Similarly, the imports at minimum load are only 75% of the amount at the average load in each season. This represents typical market behavior where market trading often peaks during the intermediate demands. At peak times, most regions are trying to meet their own demands, while at minimum demands most regions have a surplus of low-cost power. Figure E-4 shows the load duration curves before and after the imports have reduced the demands that generators see.

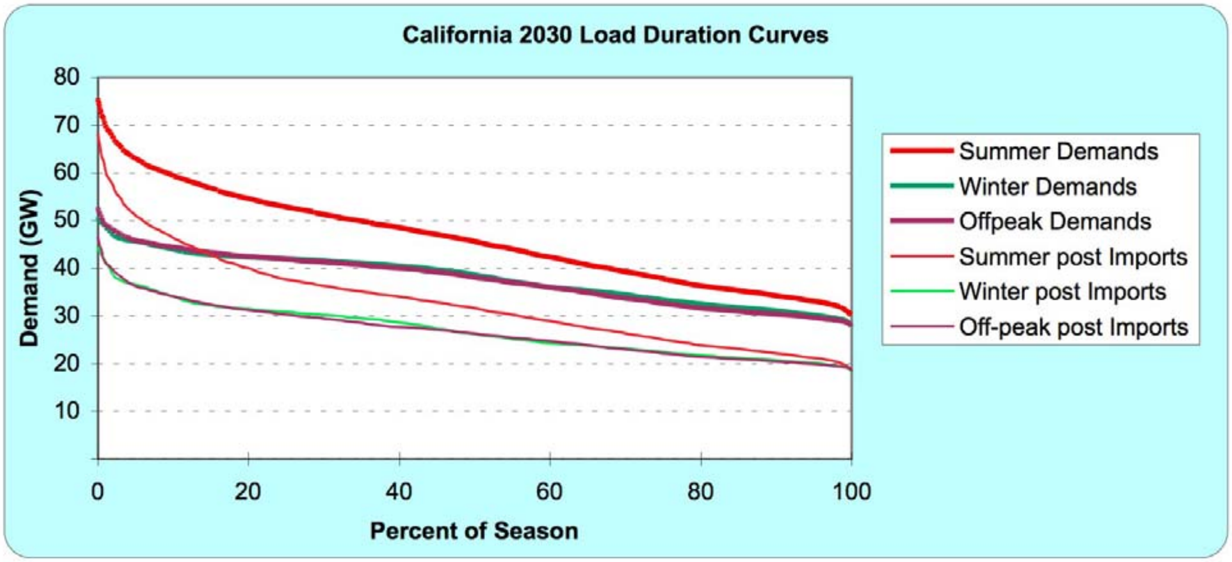

Figure E - 4: *Load duration curves for California loads before and after imports.*

California has the largest amounts of imports of any of the regions. In 2030, the difference between customer demand (355 TWh) and electric power sector generation (253 TWh) means that imports or other generation equal 29% of total customer demand.

PHEV Demand

The demand for power from PHEVs depends first on the number of PHEVs in the market. For the Phase 1 analysis, a simple straight-line growth rate in annual sales from zero in 2010 to 10% market penetration in 2030 was assumed. National sales numbers were used from the AEO2008 and assumed that 10% of vehicle sales would be in California. Allowing for retirements of older vehicles, this came out to 1.7 million PHEVs in California in 2030.

90% of the PHEVs were put into a low-voltage (110V) charging regime and 10% into high-voltage (220V) regime. A set of driving patterns was created for the vehicles in PSAT that determined the amount of battery charging needed at different times of the day. Table E-3 shows the four weekday and one weekend charging periods used. The electrical energy into the battery comes from the amount the battery was drained in the previous drive cycles. The start and end times are when owners plug in their vehicles. The timing of the initial plug-in is spread over the start and end time rather than the entire cohort of vehicles plugging in at the same time.

Table E - 3: *PHEV charging scenarios for ORCED analysis.*

	Weekday	Weekday	Weekday	Weekday	Weekend
Low Voltage					
Energy kWh	4.6	1.3	5.1	5.3	7.9
Plug-in start time	0800	1700	2200	2200	2200
Plug-in end time	0900	1800	2300	2400	2300
% of Low Volt Vehicles	5%	10%	10%	90%	100%
High voltage					
Energy (kWh)	4.6	4.6	1.8	5.3	7.9
Plug-in start time	0800	1700	2200	2200	2200
Plug-in end time	0900	1800	2400	2400	2400
% of Hi Volt Vehicles	10%	10%	10%	90%	100%

The 5% of the low-V vehicles and 10% of the high-V vehicles were set to plug in between 8 AM and 9 AM after they reach work, with a refill required of 4.6 kWh. 10% of the vehicles were also set to plug in for an hour during dinnertime. The low-V vehicles would only fill up 1.3 kWh while the high-V vehicles could recharge their full 4.6 kWh that was used driving home. At night all vehicles plug in for charging: the 90% of them that did not charge at dinner requiring 5.3 kWh, and the 10% that did charge at dinner needing less (low-V taking 5.1 kWh, high-V just 1.8 kWh). Over the weekend the plugging in would only be at nighttime and, according to the drive cycles used, would need 7.9 kWh to fully recharge the battery.

Although the batteries may need 4.6 kWh in the morning, between 5% inverter losses, 95% power factor corrections, and 10% transmission and distribution losses, the total electricity that needs to be generated is 5.4 kWh, 17% higher. Similarly, at 110V, 12 amps, the battery would see an instantaneous power level of 1.2 kW, but the correction factors raise the power level at the busbar to 1.39 kW. The 220V, 30 amp charging regime would have power levels at the battery of 6 kW but busbar power requirements of 7 kW.

By modeling the plug-in times and battery power levels, a weekly charging profile for the vehicles was created that look like Figure E-5. The vast majority of power is needed during the nighttime. Smaller amounts are needed for the morning and dinner-time charging. The weekends have larger demands in terms of kWh. The sharp peaks reflect the time that the high-V vehicles are charging a well as the low-V vehicles. The weekday demands have smaller versions of those peaks; they are not as visible because the graph displays the hourly average demand and the High-V vehicles recharge in less than an hour.

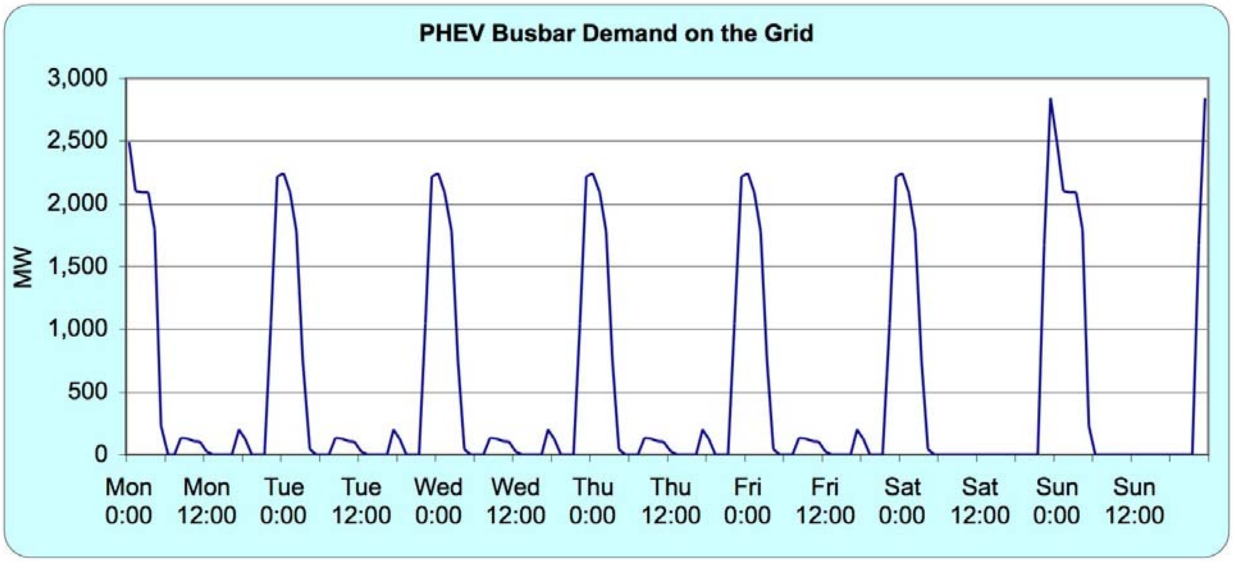

Figure E - 5: *California system demands from PHEVs.*

The weekly hourly profile in Figure E-5 is added to the base system demands shown in Figure E-3. The imported power is subtracted and new load duration curves are calculated. As to be expected, most of the impact is on the lower portion of the LDC. Figure E-6 shows the summertime LDC before and after the PHEV demands are added.

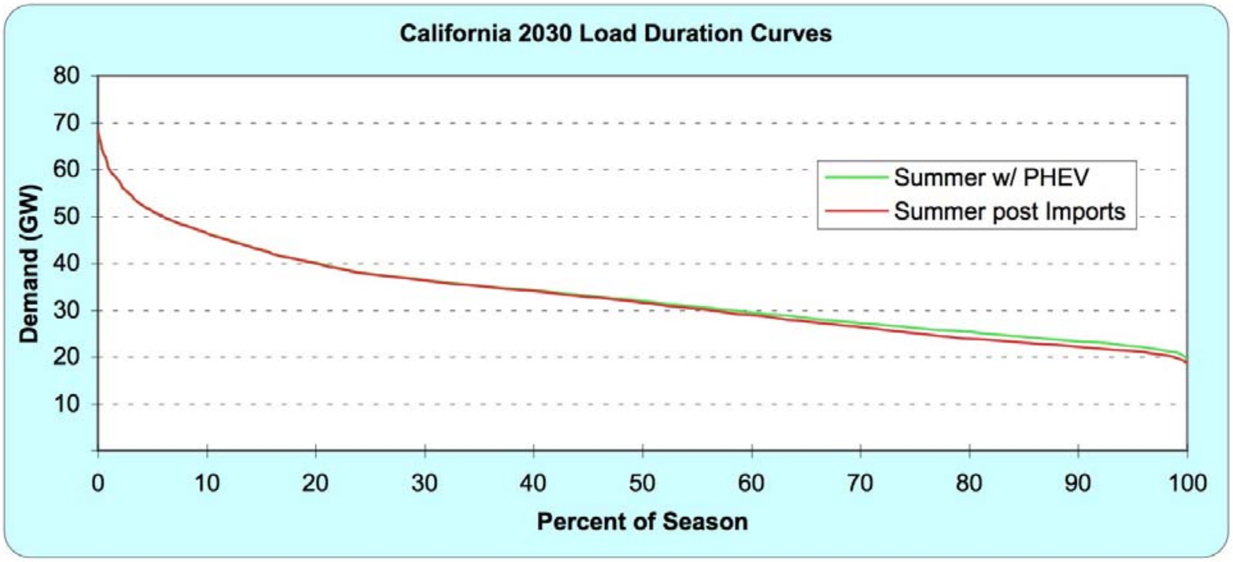

Figure E - 6: *Summer load duration curves with and without PHEV-added demand.*

Alternate scenarios that increase the charging in the dinnertime period will move the increase in demands to the left in the graph. For example, in the worst case where all PHEVs charge at 220V for an hour at dinnertime, the summer load duration curve would look like Figure E-7. While the increase only slightly raises the line above the base LDC, the impact at the peak is worse. Peak demand for the year increases 4,800 MW, from 68 GW to 72.8 GW.

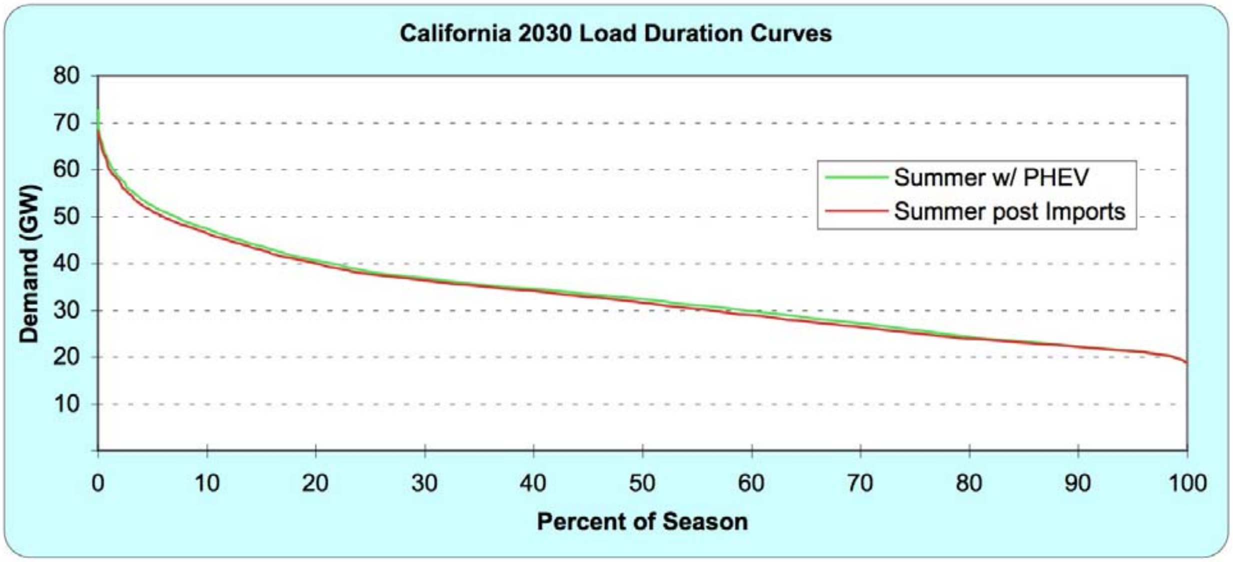

Figure E - 7: *Summer load duration curves with PHEVs charging at dinnertime and with no PHEVs.*

Dispatch Results

Once Supply and Demands have been calculated, they are transferred to the Dispatch module of ORCED. Here an intricate set of recursive and probabilistic dispatch calculations are completed to determine the amount of time each generating plant group is called upon to provide power. From this, financial and environmental impacts of the generation are determined. PHEV scenarios are compared to the base scenario to determine the impact of the added PHEV demand.

First, a reference case was run to simulate the conditions from the AEO2008. Fuel prices and policies are set to approximate the reference case and the resulting generation is compared to the official AEO2008 results. Plant parameters were changed to more closely match those results, as shown in Table E-2.

Following establishment of the reference supplies and demands, fuel prices were raised and a carbon charge (either tax or price of credits) of \$30/ton CO_2. A base case with no PHEVs was run, and the resulting wholesale electricity prices were found. These can be back-calculated to the corresponding demands to determine hourly wholesale electricity prices (Figure E-8). Prices average around 10 ¢/kWh, but at some low demand times, the prices can be between 6 and 8 ¢/kWh (the marginal cost of coal, biomass, or municipal solid waste). Daily peak prices are higher, especially in the summer when the annual peak is reached and prices climb above 40 ¢/kWh. Because gas-fired combined cycle plants are the marginal provider over 90% of the time, prices do not stray far and depend on the price of gas and efficiency of the plant. Combustion turbines are called for only at peak times.

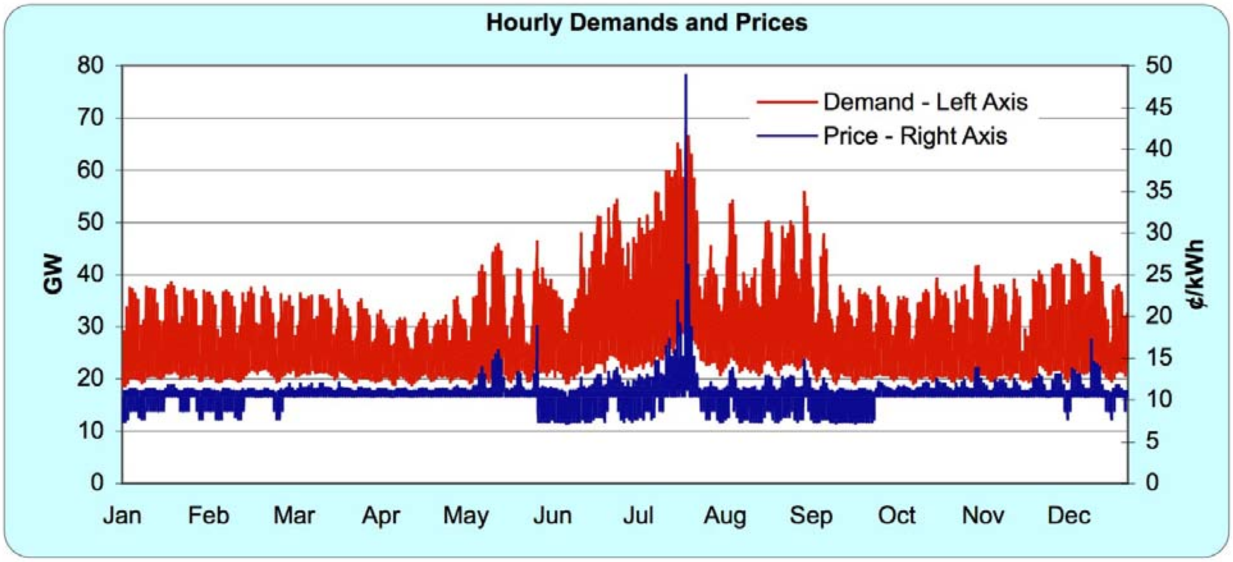

Figure E - 8: *Hourly loads to generators and corresponding hourly marginal prices.*

The same analysis was run with the LDCs that include the PHEV charging profile from Figure E-5 included. Overall prices do not change significantly, which is to be expected with the small additions. However, subtracting the results of the PHEV case from the no-PHEV case shows the marginal impact. Total generation increased by 4.63 TWh, or 1.8%. CO_2 production increased by 1,900 tons (a 2.3% increase). This is larger than the generation increase due to the large amount of carbon-free production in the base production, while the increased production is 94% gas, 6% coal, and 1% municipal solid waste.

Figure E-9 shows the capacity and generation for base case and the added generation from PHEVs. Although there is a wide mix of generation within California, the added amount from PHEVs comes almost exclusively from gas-fired combined cycle plants. This means that PHEVs operating in California are largely being fueled by clean, efficient power plants.

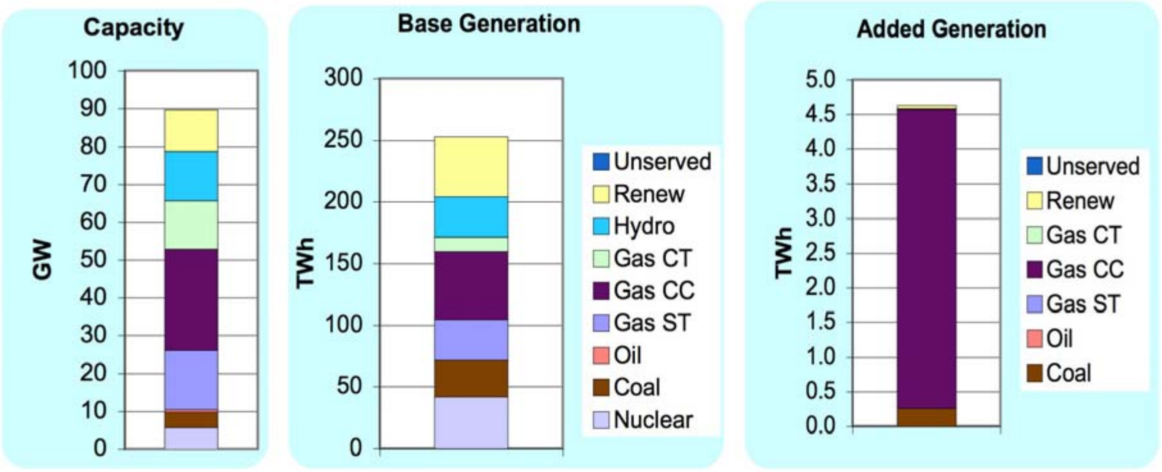

Figure E - 9: *Generating capacity, initial generation amounts, and added generation from PHEVs using the charging profile in Figure E-5.*

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APPENDIX F. Battery Life Analysis

Concept:
Accumulated charge throughput

Objective:
Determine the "damage" on the life related to each provided driving pattern / battery load profile; as a final output, the number of cycles is converted into equivalent miles/years that the battery pack could run within a capacity loss lower than 20%.

Vehicle Control Strategy:

- Charge depleting until SOC = 0.3
- Charge sustaining until SOC = ~0.3

Model Input:

- Battery Specs
- Driving cycles (speed vs. time) and habits (m/week, n/year, etc.), recharging options

Model Output:

- Energy exchanged from/to the battery, also considering energy exchanged in charge sustaining mode
- Statistics about C-rates and energy
- Estimation of life in terms of years/mile

Analyzed Drive Cycles:

- ***Trip 1*****:** UDDS+US06; daily, 5 days/wk, 48 wks/yr; represents commute to or from work. Assumes 100% SOC when leaving for work (all cases) or heading home from work (5% of cases).
- ***Trip 1b*****:** UDDS+US06; twice/day, 5 days/wk, 48 wks/yr; represents commute from work back home when no charging has occurred while at work (95% of cases); initial SOC = final SOC of Trip 1.
- ***Trip 4*****:** UDDS; 3 days/wk, 48 wks/yr; represents separate trip after work. Assumes a 1 hr dinner charge, 6-7 pm, that will reach 100% SOC after Trip 1 recharging at 220V)
- ***Trip 4b*****:** UDDS; 3 days/wk, 48 wks/yr; represents separate trip after work. Assumes no charge after work commute (initial SOC = final SOC of Trip 1b);
- ***Trip7*****:** UDDS+HWFET+HWFET+HWFET+HWFET+UDDS; 124 days/yr;

Charging Scenarios:

1. Overnight charging (1 time/day)
2. Charging at work, dinner time and overnight (3 times/day) at 220V@30A
3. Charging at work, dinner time and overnight (3 times/day) at 110V@12A

Table F - 1: Battery charging scenario #1

Event ID	Event	Description	Time [s]	Distance [miles]	Times/year	SOC i	SOC f	Energy exch. [Wh]	Tot Energy [kWh/year]
Individual Trips									
T1	Trip1	UDDS+US06 (Trip to work after full charge)	1969	15.46	240	1	0.639	4622.8	1109.5
T1b	Trip1b	UDDS+US06 (Trip to home after work)	1969	15.46	240	0.639	0.3547	4362.8	1047.1
T4b	Trip4b	UDDS (errands)	1369	7.45	144	0.3547	0.3012	2152	309.9
T7	Trip7	UDDS+HWFET+HWFET+HWFET+HWFET+UDDS (This assumes the vehicle is only recharged at the end of the day)	5794	55.93	124	1	0.304	11076	1373.4
C1b	Charge1b	Overnight charging after T1b			96	0.3547	1	8133.5	780.8
C4b	Charge4b	Overnight charging after T4b			144	0.3012	1	8807.8	1268.3
C7	Charge7	Overnight charging after T7			124	0.304	1	8714	1080.5
								Tot charging from grid	3129.7
Typical Days									
Day ID		Description	Events			Times/year		Distance [miles]	Energy exch. [kWh]
D1		3 days/week, 48 weeks/year	T1-T1b-T4b-C4b			144		38.37	19.95
D2		2 days/week, 48 weeks/year	T1-T1b-C1b			96		30.92	17.12
D3		2 days/week, 48 weeks/year + 7days/week, 4 weeks/year	T7-C7			124		55.93	19.79
							TOT (Year)	15428.92	6969.53

Table F - 2: *Battery charging scenario #2*

Event ID	Event	Description	Time [s]	Distance [miles]	Times/year	SOC i	SOC f	Energy exch. [Wh]	Tot Energy [kWh/year]
Individual Trips									
T1	Trip1	UDDS+US06 (Trip to work after full charge)	1969	15.46	480	1	0.6385	4622.8	2218.9
T4	Trip4	UDDS (errands)	1369	7.45	144	1	0.844	1877.2	270.3
T7	Trip7	UDDS+HWFET+HWFET+HWFET+HWFET+UDDS (This assumes the vehicle is only recharged at the end of the day)	5794	55.93	124	1	0.304	11076	1373.4
C1	Charge1	Charging after T1 (at work, 1 h dinner and overnight)			480	0.6385	1	4589.0	2202.7
C4	Charge4	Overnight charging after T4			144	0.844	1	1960	282.2
C7	Charge7	Overnight charging after T7			124	0.304	1	8714.0	1080.5
								Tot charging from grid	3565.5
Typical Days									
Day ID		Description	Events			Times/year		Distance [miles]	Energy exch. [kWh]
D1		3 days/week, 48 weeks/year	T1-C1-T1-C1-T4-C4			144		38.37	22.3
D2		2 days/week, 48 weeks/year	T1-C1-T1-C1			96		30.92	18.4
D3		2 days/week, 48 weeks/year + 7days/week, 4 weeks/year	T7-C7			124		55.93	19.8
							TOT	15428.92	7428.18

Table F - 3: Battery charging scenario #3

Event ID	Event	Description	Time [s]	Distance [miles]	Times/year	SOC i	SOC f	Energy exch. [Wh]	Tot Energy [kWh/year]
Individual Trips									
T1	Trip1	UDDS+US06 (Trip to work after full charge)	1969	15.46	480	1	0.6385	4622.8	2218.9
T4c	Trip4c	UDDS (errands)	1369	7.45	144	0.736	0.596	2094	301.536
T7	Trip7	UDDS+HWFET+HWFET+HWFET+HWFET+UDDS (This assumes the vehicle is only recharged at the end of the day)	5794	55.93	124	1	0.304	11076	1373.4
C1	Charge1	Charging after T1 (at work and overnight)			336	0.6385	1	4589.0	1541.9
C1c	Charge1c	Charging after T1 (1 hour at dinner, before T4c)			144	0.6385	0.736	1300.0	187.2
C4c	Charge4	Overnight charging after T4c			144	0.736	1	3316.4	477.6
C7	Charge7	Overnight charging after T7			124	0.304	1	8714.0	1080.5
								Tot charging from grid	3287.2
Typical Days									
Day ID		Description	Events			Times/year		Distance [miles]	Energy exch. [kWh]
D1		3 days/week, 48 weeks/year	T1-C1-T1-C1c-T4-C4c			144		38.37	20.545
D2		2 days/week, 48 weeks/year	T1-C1-T1-C1			96		30.92	18.4
D3		2 days/week, 48 weeks/year + 7days/week, 4 weeks/year	T7-C7			124		55.93	19.8
							TOT	15428.92	7181.1

Lifetime Estimation Considerations:

- For automotive applications (HEV, PHEV), a battery is considered “dead” when it shows capacity losses of 20% or more with respect to the original capacity.
- Manufacturers provide battery life estimation in terms of number of cycles, considering 100% DOD and ± 1C.
- Cycles with lower DOD increase the life (in terms of cycles).
- Higher C-rates decrease the life (in terms of cycles).

Table F - 4: *Charging/discharging C-rates for each analyzed driving cycle*

	C-rate(±) <=1	C-rate(±) <=2	C-rate(±) >2	C-rate(±) >3
Trip 1	73.7%	91%	9%	2.1%
Trip 1b	77.5%	92.6%	7.4%	1.7%
Trip 4	88.2%	98.5%	1.5%	0.2%
Trip 4b	86.6%	98.5%	1.5%	0%
Trip 4c	87.5%	98.6%	1.4%	0.2%
Trip 7	81%	98.8%	1.2%	0.2%

The battery is used for most of the time within C-rates lower than 2 (worst case scenario is Trip 1 with 91% of data). The negative effects of high C-rates are clearly negligible for these driving cycles.

Table F - 5: *Lifetime estimations made on energy basis.*

	Charging Scenario 1 (1 time/day)	Charging Scenario 2 (3 times/day), 220V@30A	Charging Scenario 3 (3 times/day), 110V@12A
Battery life : 4000 cycles	13.7 years (degradation 1.5%/year)	12.9 years (degradation 1.6%/year)	13.3 years (degradation 1.5%/year)
Battery life: 3500 cycles	12 years (degradation 1.7%/year)	11.2 years (degradation 1.8%/year)	11.6 years (degradation 1.7%/year)
Battery life: 3000 cycles	10.3 years (degradation 1.9%/year)	9.6 years (degradation 2.1%/year)	10 years (degradation 2.0%/year)

Conclusion: The proposed Li-ion batteries pack (260V, 45.9 Ah) presents ample lifetime to provide energy and power to a PHEV-30 for 150,000 miles (~10 years) if lifetime (in terms of cycles) is higher than 3000.

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APPENDIX G. GREET GHG Analysis

The fuel and engine assumptions for this study's GREET run are as indicated in Table G-1, followed by the assumptions for base and marginal electricity generation for southern California in 2030 in Table G-2.

Table G-1: *Fuel and engine assumptions for anticipated situation in southern California in 2030.*

Parameter	Assumption
Type of gasoline	Reformulated
Ethanol content	30% Ethanol made by gasification from woody biomass
Fuel economy of base gasoline vehicle[y]	36.48 mpg
Portion of time PHEV runs on electricity	58.8%

Table G-2: *Assumptions for base and marginal electricity for southern California in 2030.*

Fuel	Percentage of Total Electric Generation
Base Generation	
Coal	12.7
Natural Gas	37.6
Nuclear	16.9
Other (renewables, etc.)	32.8
Margin Generation	
Natural Gas NGCC	96
Coal	3
Other (Renewables)	1

The total energy used is divided into categories: feedstock, fuel, and vehicle operation representing the energy used in the processes ranging from resource recovery to refining and distribution and, finally, the end use in the vehicle. Energy is also broken down into categories of source – coal, natural gas, and petroleum. Note that negative numbers in CO_2 and GHGs represent the fact that some of the feedstocks reduce CO_2 rather than contributing to additional CO_2 emissions.

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[y] mpg assumes a 30% weight reduction of glider compared to present day baseline vehicle.

Table G - 3: *Well-to-wheel emissions for each vehicle type for southern California in 2030, assuming 10% of PHEV owners charge opportunistically.*

Item	Btu/mile or grams/mile			
	Feedstock	Fuel	Vehicle	Total
CONVENTIONAL				
Total Energy	**208**	**1,363**	**3,127**	**4,698**
From Coal	7	42	0	49
From Natural Gas	123	113	0	236
From Petroleum	69	221	2,478	2,768
Other	9	987	649	1,645
CO_2	**-42**	**21**	**239**	**218**
Total GHGs (incl. CO_2)	**-36**	**24**	**243**	**231**
HEV				
Total Energy	**141**	**927**	**2,127**	**3,195**
From Coal	4	29	0	33
From Natural Gas	84	77	0	161
From Petroleum	47	150	1,686	1,883
Other	6	671	441	1,118
CO_2	**-29**	**14**	**163**	**148**
Total GHGs (incl. CO_2)	**-24**	**16**	**166**	**158**
PHEV-30				
Total Energy	**170**	**1,461**	**1,262**	**2,894**
From Coal	2	54	29	85
Natural Gas	146	1,235	786	2,167
From Petroleum	19	28	351	398
Other	3	144	96	243
CO_2	**4.3**	**131**	**34**	**169**
Total GHGs (incl. CO_2)	**14**	**132**	**34**	**180**

Table G - 4: *Total CO_2 emissions and applicable carbon tax based on 15,425 annual miles driven.*

CO_2	Annual			Lifetime (ten yrs)		
	kg	tons	Carbon tax ($30/ton)	kg	tons	Carbon tax ($30/ton)
Conventional	3,363	3.71	$111.30	33,631	37.1	$1,113
HEV	2,283	2.52	$75.60	22,832	25.2	$756
PHEV-30	2,609	2.88	$86.40	26,087	28.8	$864

Table G - 5: *Well-to-wheel emissions for each vehicle type for southern California in 2030 (using E10 blend and assuming no weight reductions; assumes 10% of PHEV owners charge opportunistically).*

Item	Btu/mile or grams/mile			
	Feedstock	**Fuel**	**Vehicle**	**Total**
CONVENTIONAL				
Total Energy	**241**	**946**	**3,759**	**4,946**
From Coal	8	72	0	80
From Natural Gas	167	192	0	359
From Petroleum	56	303	3,517	3,876
Other	10	379	242	631
CO_2	**-2**	**39**	**288**	**325**
Total GHGs (incl. CO_2)	**7**	**42**	**292**	**341**
HEV				
Total Energy	**164**	**643**	**2,557**	**3,364**
From Coal	5	49	0	54
From Natural Gas	113	130	0	243
From Petroleum	38	206	2,392	2,636
Other	8	258	165	431
CO_2	**-1**	**27**	**196**	**222**
Total GHGs (incl. CO_2)	**5**	**28**	**200**	**233**
PHEV-30				
Total Energy	**199**	**1,557**	**1,615**	**3,371**
From Coal	3	66	31	100
Natural Gas	172	1,358	852	2,382
From Petroleum	21	54	681	756
Other	3	79	51	133
CO_2	**11**	**145**	**56**	**212**
Total GHGs (incl. CO_2)	**22**	**147**	**57**	**226**

Table G - 6: *Total CO_2 emissions and applicable carbon tax based on 15,425 annual miles (using E10 blend and assuming no weight reductions).*

CO_2	Annual			Lifetime (ten yrs)		
	kg	**tons**	**Carbon tax ($30/ton)**	**kg**	**tons**	**Carbon tax ($30/ton)**
Conventional	5,014	5.53	$165.90	50,138	55.3	$1,659
HEV	3,425	3.78	$113.40	34,248	37.8	$1,134
PHEV-30	3,271	3.61	$108.30	32,705	36.1	$1,083

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APPENDIX H. Demand Reduction Using Vehicle to Building

V2B Definition

One option for utilizing PHEVs is for owners to plug the vehicles in at their workplace when arriving in the morning. The facility can then charge the batteries when demands at the building are lower than the peak and use the power from the batteries to reduce their system peak. A corollary cost saving measure is that electricity in the low-demand morning is less expensive than in the afternoon so the building will reduce its electricity purchase cost as well.

Office Building Load Definition

To determine the potential for savings, the project team utilized the results from the *California Commercial End-Use Survey* [13] prepared for the CEC by Itron, Inc. The software DrCeus was used to model twelve different commercial sectors. The software calculates four load shapes (typical day, hot day, cold day, and weekend) for each of four seasons (winter, spring, summer, and fall). These sixteen curves present the total load in a given region for each of these sectors. The study simulated four of the largest utilities in the state, PG&E, SCE, SDGE, and SMUD.

For this study, the project team initially used the large office building summer load shapes for SCE (Figure H-1). The data represents the total floor space in the region, 227 million square feet. For this analysis, a single office building of 350,000 sq ft (roughly a 20-story building) was assumed. Converting this load shape to the demands for a single building gives the set of curves shown in Figure H-2. The curves for fall were also calculated (Figure H-3).

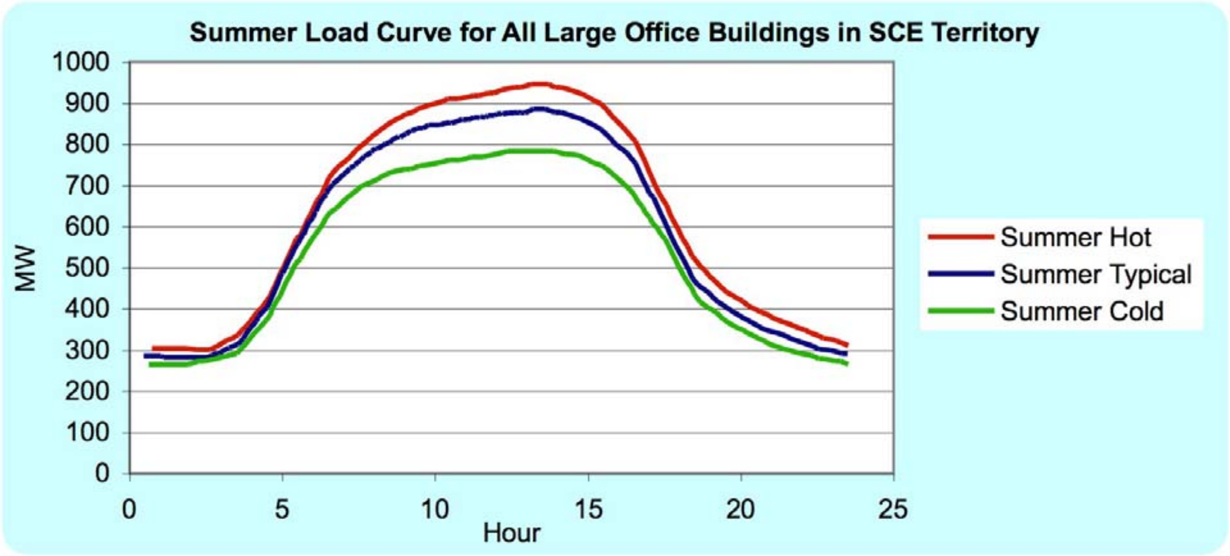

Figure H - 1: *Large office building (>30,000 sq ft) total load in SCE.*

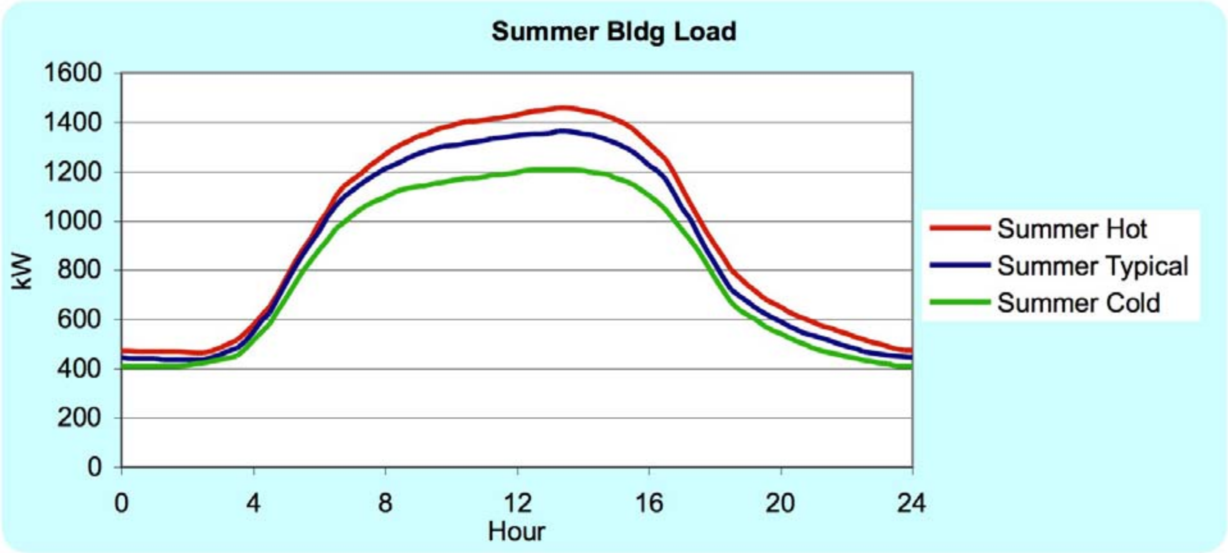

Figure H - 2: *Summer loads for single large office building in SCE.*

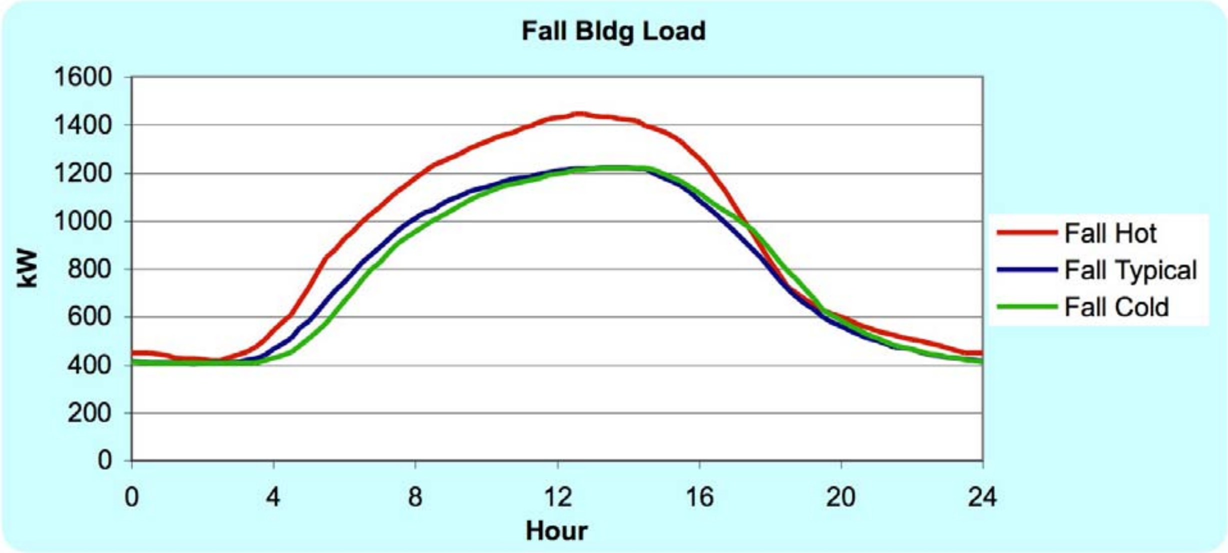

Figure H - 3: *Fall loads for single large office building in SCE.*

Extrapolation of System Load

The 2006 hourly system loads for LADWP were used to adjust the daily load for the building. Three points were found for each season: the highest daily peak, typical daily peak, and lowest daily peak. The curves in Figure H-2 above were adjusted for each day in a season based on where that day's peak fell between those three points. If the system peak for the day equaled the highest for the season, then the Summer Hot curve was used. If it equaled the average then the typical curve was used, and if it equaled the minimum then the Summer Cold curve was used. If the daily peak was in between these peaks, then the day's curve was adjusted by the percentage it was between them. This created a set of daily curves for each day of the summer.

Rate Structures

Two southern California utilities' rate structures were analyzed using this method: SCE and LADWP. The general rates for large commercial facilities were found on their websites.

SCE commercial rates structures are broken into both a demand and energy portion. The rates can vary based on the time of day and season in which they occur. Table H-1 shows the rates used for this analysis based on the Schedule TOU-8, Time of Use – General Service – Large published on the SCE website. The summer season is June through September, while winter season is all other months. The analysis did not cover all of the intricacies of the rates, such as the combination of utility retained generating (URG) and Department of Water Resources energy rates.

Table H - 1: *SCE TOU-8 rates.*

	Peak	Mid-peak	Off-peak
Time	1200-1800 summer weekdays	0800-1200,1800-2300 summer weekdays 0800-2100 winter weekdays	All other
Demand Charge	$10.21/kW – facilities + $15.48/kW - generation	$10.21/kW – facilities + $5.24/kW – generation	$10.21/kW – facilities
Energy Charge	1.439 ¢/kWh – delivery +10.053 ¢/kWh – generation	1.439 ¢/kWh – delivery +7.294 ¢/kWh – generation	1.439 ¢/kWh – delivery +3.673 ¢/kWh – generation

http://www.sce.com/NR/sc3/tm2/pdf/ce54-12.pdf

The LADWP rates used in this study have different hours and season definitions. The rates used are shown in Table H-2. Their high season is June through October and low season is November through May. Different demand prices were used for peak and mid-peak periods in the high and low seasons rather than only having the peak during the summer season as with SCE.

Table H - 2: *LADWP large general service rates.*

	Peak	Mid-peak	Off-peak
Time	1300-1700 weekdays	1000-1300,1700-2000 weekdays	All other
Demand Charge per kW	$2.25/kW – facilities + $0.46/kW - ESA + $8.63/kW – high season or $7.90/kW – low season	$2.25/kW – facilities + $0.46/kW - ESA + $4.21/kW – high season or $3.85/kW – low season	$2.25/kW – facilities + $0.46/kW - ESA + $1.40/kW
Energy Charge	4.24 ¢/kWh – ECA +2.949 ¢/kWh – generation	4.24 ¢/kWh – ECA +2.907 ¢/kWh – generation	4.24 ¢/kWh – ECA +1.658 ¢/kWh – generation

http://www.ladwp.com/ladwp/cms/ladwp001753.jsp

PHEV Utilization Simulation

When vehicles are on site, the building owner can charge them during the morning hours and thereby raise the power level for the building. In the afternoon, the building owner could drain the batteries by an equal amount, in order to lower the power level for the building. The algorithm used solved for the amount of charging needed so that the total energy was the same but the load curve was flattened across the hours from 8 AM to when the unadjusted load profile dropped below this average amount (Figure H-4).

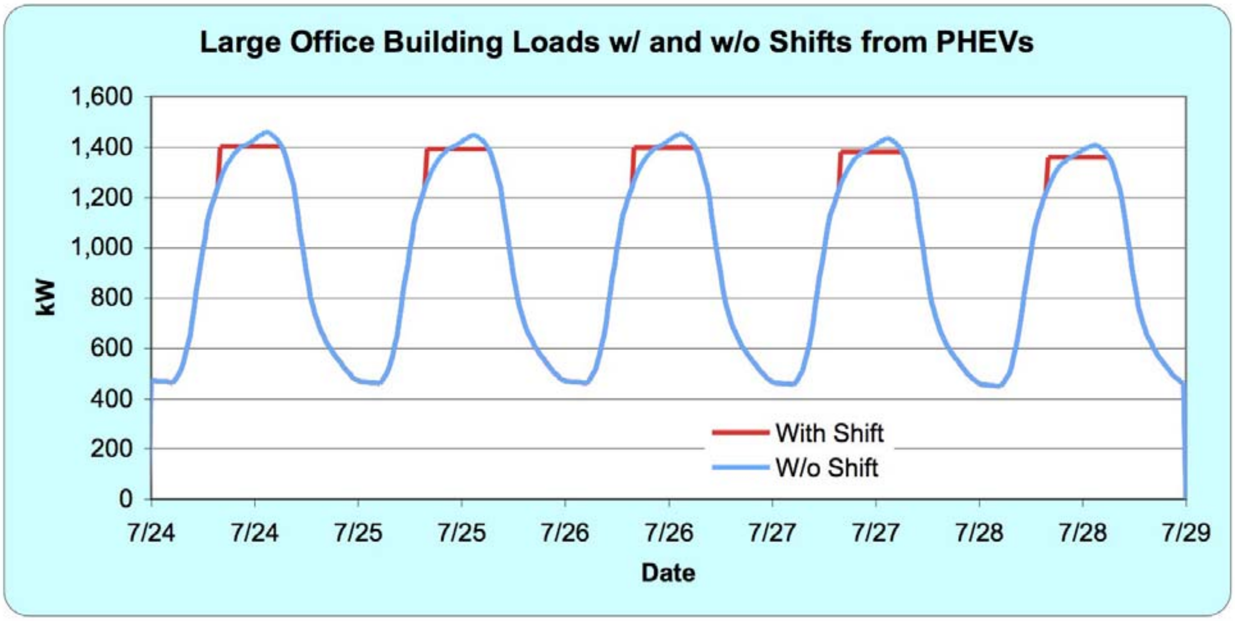

Figure H - 4: *Change in load shape for July 24-29 with PHEV charging used for peak shaving.*

Vehicles were assumed to begin arriving at 8 AM and have their batteries drained by an average of 4.589 kWh, as defined by the driving cycle used. Sufficient vehicles would be on site to be able to fully take the amount of energy needed to be stored in the morning hours and released in the afternoon. The building required a minimum of ~35 vehicles to supply the capacity needed for the peak shaving.

Results

Applying the SCE prices to the change in the profile for July gave the results shown in Table H-3. Total savings for the month were $2100, mostly from the savings in demand payments. Using the LADWP rates for the same month resulted in a savings of only $1100, also mostly from the demand payment reductions. Two other months were examined: August and October. Savings to the facility were between $1000 and $2000 in both months using the SCE and LADWP rates.

Table H - 3: *Effect of PHEV peak shaving in July using SCE rates.*

	No PHEV	PHEV used	Difference
Peak Demand (kW)	1458	1401	-57.2
Energy Cost (k$)	185.4	185.2	-0.3
Demand Cost (k$)	59.5	57.6	-1.8
Tot cost (k$)	244.9	242.8	-2.1

A similar sensitivity involved starting the charging at 7 AM instead of 8 AM. With the extra time, more batteries can be charged in the morning, and the peak can be lowered around 80 kW, whereas it was reduced only ~60 kW in the scenario above. The savings using the SCE rates doubles to $4,000 per month, though the number of PHEVs needed also doubles to around 70.

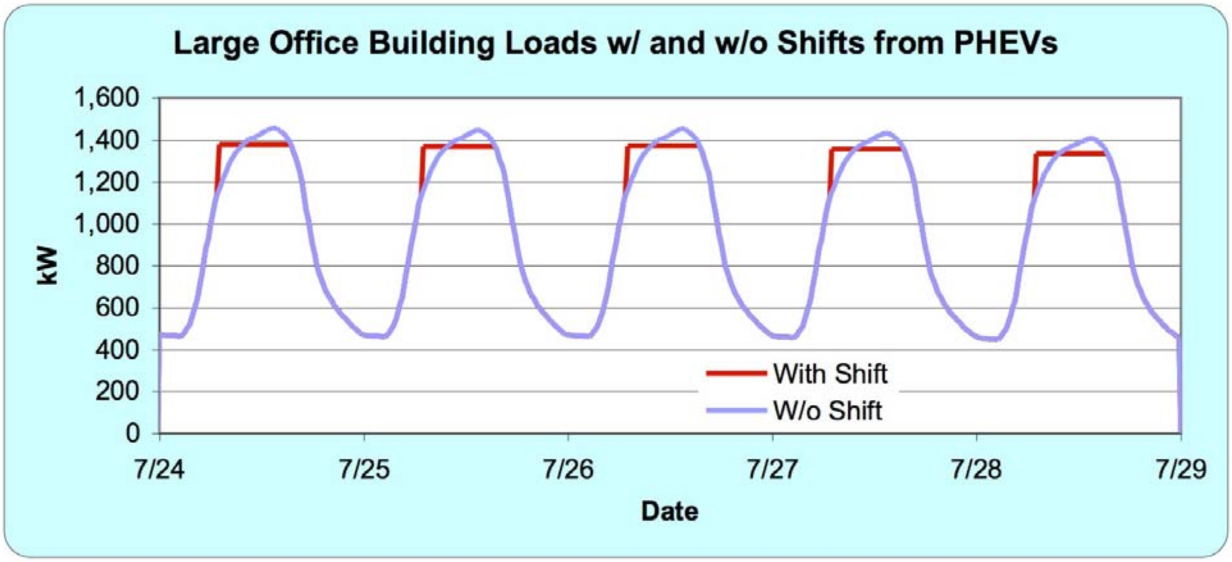

Figure H - 5: *Change in load shape with PHEVs plugging in beginning at 7 AM.*

A possible conclusion from this analysis is that the savings potential, while real, is not very significant for a large facility. $2000 per month of savings is only ~1% of the electricity bill, and this amount does not cover the costs of installation or operation of the charging stations. Nor does it include any payment as incentive to the PHEV owners for their loss of battery life. The savings over 35 vehicles works out to $30-$60 per month per vehicle. If the savings were split with vehicle owners, then they would likely receive around $250 per year. This may or may not be a sufficient amount to entice some vehicle owners to offer their batteries. Encouraging earlier arrivals so charging can begin earlier will help the overall savings, but the number of required vehicles will increase accordingly.

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APPENDIX I. Common Criticisms

Q: Why choose the 2030 time horizon instead of 2020, which may be more predictable?

A: Originally, 2020 was anticipated for this study since early generation PHEVs are expected to be mass produced by this time. However, workshop feedback indicated that complementary technologies of interest (e.g., V2B, V2G) were unlikely to be mainstream by 2020. With many potential value propositions associated with these technologies, it was recommended that the project team extend the time horizon to 2030.

Q: What about the effects of PHEVs in regions outside southern California?

A: Since southern California likely presents an optimal scenario for the PHEV market, alternative regions will be studied to account for the nation's diverse range of generation mixes, climates and other variables. A second case study is currently planned for a region with a high coal-fired generation mix, such as the Tennessee Valley. Additional value may also be derived from studying regions with either highly diversified or nuclear-rich generation mixes.

Q: Why was a PHEV-30 chosen for this study? How does this compare to other PHEVs with other AERs (PHEV-15, PHEV-40)?

A: PHEVs with a 30 mile AER were chosen to be analyzed in this study as a direct result of workshop feedback. However, PHEVs with a variety of AERs (e.g., PHEV-15, PHEV-40) are expected to exist in the 2030 market. For this particular case study, only PHEV-30s were analyzed. However, an upcoming Sensitivity Study of the southern California region will broaden the results of this study by investigating PHEV-15s and possibly additional AERs and series PHEVs.

Q: Why was E30 chosen as the liquid fuel in this study? Were other fuel mixes considered?

A: With guidance from workshop participants, the project team that 30% of transportation fuel will be cellulosic ethanol. This projection also aligns with President Bush's 2006 Advanced Energy Initiative. For modeling purposes, this assumption was approximated by inputting an average blend of E30 into PSAT and GREET; however, this does not necessarily translate to E30 as the dominant fuel in 2030. For basic comparison purposes, all three vehicle types were also analyzed using an E-10 average blend. A broader range of fuel mixes will be investigated in a future Sensitivity Study of the southern California region.

Q: Were additional costs included to account for the 30% weight reduction in all three vehicle types?

A: To achieve a 30% vehicle weight reduction (as outlined in the DOE GPRA Study Results) and fuel efficiency of 35mpg, an incremental cost across the board for all three 2030 vehicle types is likely. In this study, the incremental cost was assumed to be roughly the same for all three vehicles types, therefore, it did not have a significant effect on the overall vehicle purchase cost differences.

Q: What actions must take place to reach a 10% market penetration rate by 2030?

A: A Market Introduction Study is currently underway to identify action items that are critical to creating and sustaining a 10% market penetration rate for PHEVs once they are available for purchase. The project team will investigate what policies, incentives, and regulations are likely to be key enablers to accelerate commercialization of PHEVs. Critical supply chain and market pinch points capable of limiting the success of the PHEV market will also be identified.

Q: Why were time-differentiated electricity rates not used to calculate electric fuel costs?

A: Actual time-differentiated electricity rates could not be obtained for the southern California region. Therefore, an average cost per kWh of electricity consumed by PHEVs (mostly during off-peak hours) was estimated using the regional generation mix data. Since gas-fired combined cycle plants are most likely to set the wholesale price when PHEVs would primarily be charging, the project team used the efficiencies for the region's different plants and a natural gas price of $14/mmBtu (double of the AEO2008 reference price) to estimate an average wholesale price of electricity during off-peak hours to be 8.3¢/kWh *(this is prior to applying a carbon tax to the electricity rate). In addition, a 10¢/kWh for delivery services was included, similar to the price that some California utilities use for their current electric vehicle rates. Therefore, an average off-peak electricity rate of $0.183/kWh was used in this study.*

Q: Why is a 14kWh battery needed when only approximately 8kWh will be utilized?

A: To achieve a ten year (~150,000 mile) life, certain abuses must be avoided. For example, the battery must not be overcharged; therefore, a safety margin of 5% capacity was added to avoid operation above 95% SOC. Similarly, if Li-ion cells are discharged or operated at a level lower than ~25% SOC, their efficiency and performance is degraded, plus significant heating and aging will occur. Therefore, a "No operation region" has been established in this study to avoid operation below 25% SOC. Finally, an annual degradation of 2% is accounted for on the front end to ensure a 30 mile AER throughout the entire lifetime of the battery; this essentially makes the vehicle a PHEV-35 in the initial years of operation. Therefore, the battery with a 7.8 kWh operating range (needed for a 30 miles AER) was sized at 14kWh to accommodate the combined safety margin, "no operation region", and degradation buffer.

Q: Has a disposal fee for end-of-life batteries been considered or included in this study?

A: A disposal fee was not included in this study, because various utilities have displayed significant interest in acquiring end-of-life PHEV batteries as soon as they become available for use in secondary applications. Such secondary applications include load leveling, transmission support, renewables firming, etc. Unlike lead-acid batteries that only offer materials salvage via recycling at end-of-life, lithium-ion batteries have years of application remaining beyond automotive use. Therefore, this study assumes no disposal fee to the vehicle owner.

Q: Is the battery cost assumption for 2030 realistic?

A: The 2030 battery cost assumption was derived from DOE's 2008 FCVT Multi-Year Program Plan. Based on preliminary feedback of this report, some have considered the cost target to be quite aggressive while others believe the target will be met long before 2030. Overall, this study's battery cost assumption appears to fall within this spectrum of feedback.

Q: Have various "types" of travelers that result in a broad VMT range been included in this study?

A: The collection of drive cycles used in this study was chosen to best represent the average commuting behavior of southern California drivers. While individual PSAT simulations were not run on individual "types" of drivers (e.g., Driver A, Driver B), the average commuting style used in this study accounted for overnight charging, a percentage of opportunistic charging, and a variety of driving distances throughout the week ranging from short all-electric trips to longer weekend trips of over 100 miles.

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