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Plug-In Hybrid Electric Vehicle
Value Proposition Study

Phase 1, Task 3:
Technical Requirements and Procedure for Evaluation of One Scenario

June 2008

SENTECH, INC   THE OHIO STATE UNIVERSITY   CAR   OAK RIDGE National Laboratory   EPRI   GE

ORNL/TM-2008/068

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ACKNOWLEDGEMENTS

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Phase 1, Task 3 Report – June 2008

1. INTRODUCTION

1.1. Review of Task 2 Activities

In Task 2, the project team designed the Phase 1 case study to represent the "baseline" plug-in hybrid electric vehicle (PHEV) fleet of 2030 that investigates the effects of seventeen (17) value propositions (see Table 1 for complete list). By creating a "baseline" scenario, a consistent set of assumptions and model parameters can be established for use in more elaborate Phase 2 case studies.

The project team chose southern California as the Phase 1 case study location because the economic, environmental, social, and regulatory conditions are conducive to the advantages of PHEVs. Assuming steady growth of PHEV sales over the next two decades, PHEVs are postulated to comprise approximately 10% of the area's private vehicles (about 1,000,000 vehicles) in 2030. New PHEV models introduced in 2030 are anticipated to contain lithium-ion batteries and be classified by a blended mileage description (e.g., 100 mpg, 150 mpg) that demonstrates a battery size equivalence of a PHEV-30. For a complete description of the PHEV vehicle modeling parameters and fleet characteristics of 2030, see the Phase 1, Task 2 report at www.sentech.org/phev.

1.2. Overview of Task 3 Activities

Task 3 includes the determination of data, models, and analysis procedures required to evaluate the Phase 1 case study scenario. Some existing models have been adapted to accommodate the analysis of the business model and establish relationships between costs and value to the respective consumers. Other data, such as the anticipated California generation mix and southern California drive cycles, have also been gathered for use as inputs. The collection of models that encompasses the technical, economic, and financial aspects of Phase 1 analysis has been chosen and is described in this deliverable. The role of PHEV owners, utilities (distribution systems, generators, independent system operators (ISO), aggregators, or regional transmission operators (RTO)), facility owners, financing institutions, and other third parties are also defined.

2. PHEV VPS DATA FLOW

Figure 1, shown on the following page, visualizes the summary of data flow that helps guide the Phase 1 analysis process. Starting from the left of the diagram, "inputs" are fed into their designated "models" for simulation. Useful "outputs" from these models either feed back as additional inputs to complementary models or continue 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. These conclusions will be documented in the June 2008 "interim report." Immediately following Figure 1, the roles of the major process components are briefly described.
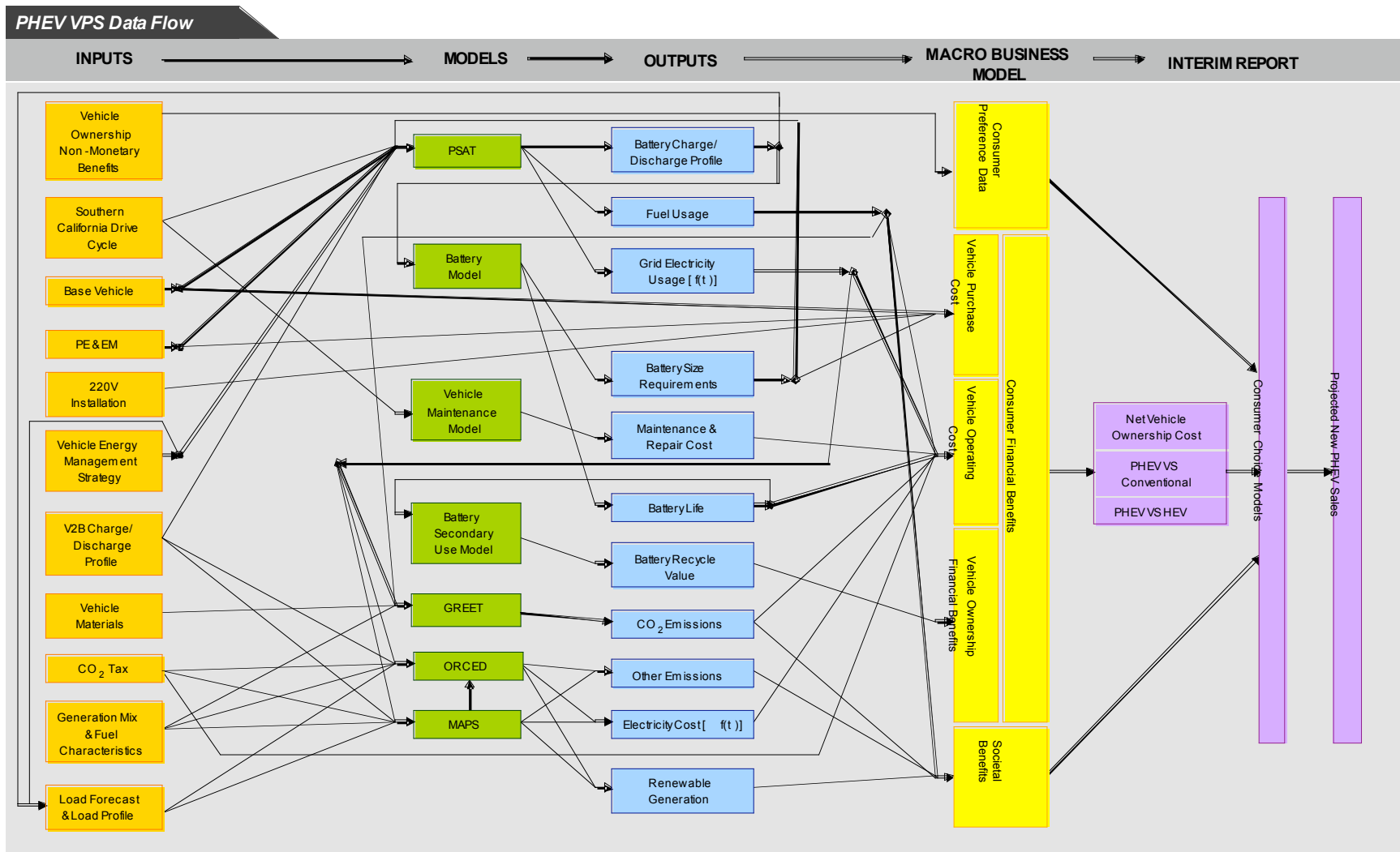
Figure 1: *Network of Data Flow Used in Phase 1 Case Study Analysis*

2.1. Inputs

To obtain all desired outputs for the Phase 1 case study, a list of required inputs (shown in Figure 1) was first constructed. Since the overarching business model will compare a PHEV to both a hybrid electric vehicle (HEV) and conventional vehicle, specific properties of each vehicle type must be known to properly calculate desired outputs (e.g., fuel usage, emissions). Such properties include the base vehicle framework, breakdown of vehicle materials used, the extent of power electronics and electric machinery (PE & EM) used, and the vehicle energy management strategy. Specific to the southern California region, project team members obtained input information on the anticipated drive cycles, generation mix, fuel characteristics, and a projected CO_2 tax for 2030. For vehicle to building (V2B) applications, charge/discharge profiles of PHEVs arriving and parking at work has also been determined and used to help predict load forecasts and profiles. Finally, the project team compiled a set of non-monetary value propositions in need of statistical consumer survey data.

2.2. Models

A collection of modeling tools and techniques has been carefully chosen to appropriately analyze all inputs and calculate all desired outputs for the Phase 1 case study. Selected models have been borrowed from national laboratories, private industry, and government agencies. In some cases, models have been modified to obtain all relevant data. A brief description of each model is provided below.

2.2.1. PSAT (Powertrain Systems Analysis Toolkit)

PSAT is a vehicle level modeling tool that simulates fuel economy and performance in a "real world" manner, accounting for transient behavior and control system characteristics. Conventional, battery electric, fuel cell, series hybrid, parallel hybrid, and power split hybrid configurations can all be simulated using PSAT. For this case study, the project team will develop appropriate vehicle models using PSAT and subject them to a variety of inputs (e.g., base vehicle component data, PE & EM data, drive cycle data, V2B charge/discharge profiles, and vehicle energy management strategy information) to properly simulate battery charge/discharge profiles, and fuel usage.

Model Source: Argonne National Laboratory (ANL)

2.2.2. PHEV Battery Model

A PHEV battery model was developed for this study through a collaborative effort between the Ohio State University Center for Automotive Research (OSU-CAR) and General Electric (GE) Global Research Center. The model is based on the concept of accumulated charge throughput. This simplified approach was favored over a more complex model which accounted for temperature, applied cell voltages and deep discharge effects due to time constraints and proprietary model sets.

Most electrochemical batteries have a linear degradation in effective capacity when operated over a 100% depth of discharge cycle. The number of cycles accomplished before a 20% loss in capacity is then determined to be the number of cycles to end of useful life. This PHEV study used this charge throughput product of cycles multiplied by capacity to estimate the degradation of the battery under various driving cycles and scenarios. The PHEV operation scenarios came from the PSAT simulations in the form of electrical power charge and discharge profiles over various driving schedules.

Note that all partial and deep discharges during the course of the PSAT driving cycles were given equal weighting of charge throughput degradation. Further refinement to this model may be made to account for the reduced stress of partial, or micro-cycles on the battery, as supported by recent HEV operation data. To take the depth per charge cycle into account, a cycle depth multiplier is introduced which gradually increases the micro cycle life as compared with the macro cycle life. The objective is to determine the "damage" per charge exchange over a given driving pattern.

Model Source: OSU-CAR; GE Global Research

2.2.3. *Electric Vehicle (EV) Battery Secondary Use Study*

The 2003 study "Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications" presents a methodology to assess the value associated with applying "end of useful life" EV batteries in various stationary applications. Possible barriers to EV battery reuse and necessary preparation of used EV batteries for a second application are also evaluated. Cost estimations of acquiring, testing, and reconfiguring the used EV batteries are performed. Economic feasibility is determined by calculating a life cycle cost of a battery energy storage system for each application and then evaluated against the expected economic benefit.

This study will provide a basis for assigning an appropriate recycling value for comparable PHEV batteries that are no longer suitable for use in vehicle operations. Feasibility of additional value-added stationary applications may also be explored using this study's methodology. For example, used lithium-ion batteries may have enough capacity to augment residential solar applications at reduced cost compared to new batteries, potentially contributing to the U.S. Department of Energy's (DOE) Solar America Initiative.

Report Source: Sandia National Laboratories (SNL)/Sentech, Inc.

2.2.4. *GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation)*

The full life-cycle GREET model allows researchers to evaluate various engine and fuel combinations for individual calculations of fuel-cycle energy consumption, greenhouse gas emissions (primarily CO_2, methane and nitrous oxide), and five criteria pollutants (volatile organic compounds, carbon monoxides, nitrogen oxide, specific particulate matter, and sulfur oxides). GREET will be primarily used in the Phase 1 case study to calculate the potential CO_2 emissions reductions in California as a result of the southern

California PHEV fleet. To obtain this value, researchers will supply GREET with information on the vehicle construction and operational parameters, regional generation mix, and PSAT feedback (e.g., fuel type/usage and grid electricity usage). The GREET model is publicly available as a Microsoft Excel spreadsheet on ANL's Transportation Technology R&D Center webpage.

Model Source: ANL

2.2.5. *ORCED (Oak Ridge Competitive Electricity Dispatch)*

ORCED analyzes the electricity supply system for a given region or utility system based on power generating plant information and the region's hourly electric load demands. Based on the plant dispatch information, fuel costs and the region's power demands, ORCED will be used in this case study to calculate plant emissions, electricity costs as a function of time, renewable energy additions to the generation mix, and other operational factors of the California electricity market. To obtain these outputs, information on anticipated generation mix, load forecast/profile, V2B charge/discharge profile, and grid electricity usage (previously simulated in PSAT) will be inputted into ORCED. Like GREET, this model is also publicly available as a Microsoft Excel spreadsheet on the ORCED webpage.

Model Source: Oak Ridge National Laboratory (ORNL)

2.2.6. *MAPS (Multi Area Production Simulation)*

MAPS is a detailed simulation model that calculates hour-by-hour energy production costs with respect to generation dispatch constraints imposed by the transmission system. MAPS calculates real power flows for each generation dispatch by using a detailed electrical model of the entire transmission network in addition to generation shift factors determined from a solved AC load flow. MAPS can also model the effects on expected generator dispatch of specific ancillary services requirements. In this way, the economic effects of re-dispatching the generation needed to maintain transmission line flow limits and security constraints can be determined. MAPS can be used to simulate changes in plant emissions, electricity costs, and the amount of renewable energy in the generation mix for specific regions within the California Independent System Operator (CAISO) system by modeling a subset of the generators, transmission system, and loads in more detail.

In subsequent phases of the study, when additional vehicle to grid (V2G) value propositions will be evaluated, such as the ability of a PHEV fleet to provide ancillary services to the grid, the MAPS output for southern California region power plant dispatch will be used to adjust parameters and inputs in the ORCED model for dispatch of the CAISO system.

Model Source: GE Global Research

2.2.7. *Vehicle Maintenance Model*

Scheduled maintenance costs contribute significantly to a vehicle's overall operating costs over its lifetime. These scheduled maintenance values will be referenced from the Electric Power Research Institute's (EPRI) 2002 "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles" for conventional, HEV, and PHEV vehicles. Values from this study may be modified to account for inflation and scaling to a mid-size sedan. It should be noted that the increased number of powertrain components susceptible to failure is greater in PHEVs; 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.

Report Source: EPRI

2.3. **Outputs**

As demonstrated in Figure 1, each model contributes to one or more outputs. In some cases, initial outputs from the aforementioned models provide feedback to complementary models. Otherwise, relevant output continues downstream to feed the MBM. Outputs range from individual vehicle characteristics (e.g., fuel usage, maintenance/repair data, battery size requirement, and battery recycling value) to regional effects (e.g., grid electricity usage, emissions, and generation mix). See section 2.2 to review which models are responsible for which outputs.

2.4. **Macro Business Model**

Once all desired outputs have been obtained from each model, they will enter into the MBM, which is comprised of six primary components described below.

2.4.1. *Consumer Preference Study Data*

The project team has gathered consumer preference data related to PHEVs from various national laboratories and universities for use in the MBM. These entities have conducted extensive surveys that estimate the value, or worth, of individual potential PHEV attributes. Common survey questions examine whether an individual would be willing to pay extra for a specific new vehicle attribute, and, if so, at what premium? With this consumer preference data, the project team can assign monetary values to several propositions (e.g., emergency back-up power, convenient charging locations, ability to plug in from any outlet) that will help estimate the percentage of consumers who would purchase a vehicle with these attributes. Ideally, these attributes will provide the additional value needed for PHEVs to reach the anticipated 10% market penetration by 2030.

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

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2.4.2. *Consumer Financial 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 will also be 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, reduced CO_2 emissions tax, maintenance/repair costs), and
3. Vehicle Ownership Financial Benefits (e.g., battery recycling credit)

Consumer financial benefits will be combined with consumer preference data and societal benefits to comprise the MBM for Phase 1.

Model Source: Sentech, Inc.

2.4.3. *Societal Benefits*

The nationwide effects that are expected as a result of PHEVs will be accounted for in the societal 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 ultimately decrease the country's dependence on foreign oil while strengthening national security. Similarly, reduced greenhouse gas or other emissions from PHEVs may ultimately improve air quality and climate change efforts. Finally, increased amounts of PHEVs plugged in during off-peak hours could 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 renewable portfolio standards (RPS).

Source: Sentech, Inc.

2.4.4. *Utility Benefits*

Several potential benefits to the utility will be investigated in the Phase 1 case study. Interactions between the semi-dispatchable PHEV recharge loads and the daily operational characteristics of a regional grid will be observed to determine cost savings to the utilities (capital and/or production). The operational issues of renewable curtailment, economic dispatch of generation assets, and loading of generation assets will also be analyzed. Potential elevations in the penetration of renewable energy resources in the 2030 timeframe will be researched in concert with the presence of PHEVs as loads, using hourly load profile data, PHEV recharge profiles, and typical renewable energy production characteristics.

2.4.5. *Commercial Building Owner Benefits*

Commercial building owners may use V2B to utilize commuter vehicles driven to urban areas as a way 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 will be 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 of a small PHEV fleet.

2.4.6. _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 reducing the expected lifetime of the energy storage system and/or having a third party (someone other than the auto manufacturer or the consumer) own the batteries available for lease to the consumer. Investigation into alternative battery ownership options will begin in Phase 1 and will continue into future phases.

2.5. **Interim Report**

The June 2008 Interim Report will present what the project team has calculated to be the projected percentage of consumers in the southern California region that will choose to buy the baseline PHEV model defined in the Phase 1 case study. To obtain this value, ORNL researchers will enter results of the MBM into a "consumer choice model" capable of projecting the new PHEV sales in 2030 in the region. Researchers at ANL and UMTRI will also perform similar projections based on the same MBM results.

3. EVALUATION OF VALUE PROPOSITIONS

The outputs shown in Figure 1 provide the basis for analyzing the seventeen (17) value propositions chosen for Phase 1 investigation. Table 1 below lists all of these value propositions along with the lead investigator(s), modeling requirements, applicable output, and application of output.[1] Following this summary table, each value proposition is individually broken down to explain the anticipated process in more detail.

Table 1: Phase 1 value propositions and anticipated 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.	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 CA	Reduction in petroleum use per vehicle	Address national strategic goals

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

9.	Emissions reduction	Sentech, Inc.	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	ORCED, 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	ORCED, MAPS	Change in cost of electricity for CAISO	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 State of California, Vehicle model combo	Reduced commercial building billing demand charge	Assign a monetary value to proposition

3.1. Vehicle Ownership Benefits

3.1.1. Fuel Cost Savings (with GPS-enabled fuel optimization dispatch)
- Required data and/or model(s): *PSAT; southern California driving data*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Blended mileage operating cost*
- Use of output: *Quantify PHEV operating cost savings*

Fuel cost savings is directly proportional to fuel displacement, and thereby fuel consumption. Using PSAT, fuel consumption can be modeled by simulating vehicles over drive cycles analogous to typical driving patterns in the study location. Several potential resources, including Southern California Edison (SCE), NREL, and UMTRI, may be accessed to collect actual driving data of the study location. Driving data will include information such as vehicle speed vs. time, acceleration, location, and where the vehicle is parked vs. time of day.

It is common knowledge that vehicle speed and acceleration have a significant impact on fuel consumption. However, both ANL and NREL researchers have also shown a potential for improvement using route-based control using GPS for route prediction. Based on modeling and simulation results from ANL, it has been shown that for distances beyond the all-electric range of the vehicle, the optimal control strategy is a blended operation. Additionally, by using "opportunistic" charging when available, the fuel displacement can be further increased. These study results in conjunction with the required driving data will aid in optimizing fuel economy and thus fuel cost savings. Fuel cost savings will then be calculated based on Energy Information Administration (EIA) projections as well as the December 2007 PHEV Value Proposition Workshop predictions of fuel and oil prices.

3.1.2. Tailgate/camping, limited household appliance backup (residential V2B)
- Required data and/or model(s): *Consumer Preference Data from NREL*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Associated level of value for consumer*
- Use of output: *Assign a monetary value or estimated market size to proposition*

Stored energy in PHEV batteries is valuable to consumers who wish to power limited appliances away from home (e.g., TVs or mini-fridges at tailgates, campsites) or during unexpected temporary power outages (e.g., refrigerator, television, computer), removing the need for costly electric generators. The Opinion Research Corporation International (ORCI) has collected survey data for NREL that reports the percentage of individuals that would be willing to pay a cost premium for this option, and, if so, the amount of extra money they are willing to spend to have it. Sentech will work with NREL/ORCI to obtain this specific data set and estimate its average quantitative value or estimated market size.

3.1.3. Opportunistic charging from any outlet for portion of fleet
- Required data and/or model(s): *Consumer Preference Data*

- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Associated level of value for consumer*
- Use of output: *Assign a monetary value or estimated market size to proposition*

The convenience to charge a PHEV at any time of the day (as opposed to suggested off-peak hours) from any outlet (e.g., home, friend's house, airport) are both valued by potential PHEV owners, and many may pay a premium to have this freedom of choice. The project team is evaluating consumer preference survey data available from several potential resources, including UMTRI, UC Davis, and NREL, that demonstrates the percentage of individuals that would be willing to pay a cost premium for these conveniences, and, if so, the amount of extra money they are willing to spend to have them. Sentech will work with these organizations to obtain this specific data set and estimate its average quantitative value or estimated market size. Some benefits from opportunistic charging are expected to overlap with those from convenient charging locations described in 3.1.5. since consumers would be able to charge at any of these convenient locations whenever the consumer desires.

3.1.4. Reduced vehicle maintenance costs
- Required data and/or model(s): *Operating cost calculations from EPRI Report[2]*
- Lead investigator(s): *EPRI*
- Applicable output: *Expected reduction in scheduled maintenance cost with PHEV*
- Use of output: *Reduce net cost of PHEV*

PHEVs have been speculated to have lower scheduled maintenance costs relative to conventional vehicles and HEVs for several reasons. For instance, PHEV engines are operating for a lower percentage of the vehicle operating time; therefore they may have longer intervals between oil changes and air filter replacements. Regenerative braking on HEVs and PHEVs reduces brake wear and the need for brake pad/shoe replacements. The project team will project scheduled maintenance costs for all three vehicle types using the Vehicle Maintenance Model, which pulls values from EPRI's 2002 "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles." Values from this study may be modified to account for inflation and scaling to a mid-size sedan. It should be noted that the increased number of powertrain components susceptible to failure is greater in PHEVs; therefore, it is not unreasonable to assume that *unscheduled repair costs* will be higher relative to HEVs and conventional vehicles, potentially canceling out cost savings from scheduled maintenance resulting from PHEVs.

3.1.5. Convenient charging locations (e.g., at airports, municipalities, etc.)
- Required data and/or model(s): *Consumer Preference Data*
- Lead investigator(s): *Sentech, Inc.*

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[2] "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options for Compact Sedan and Sport Utility Vehicles." Technical Report - 1006892. Electric Power Research Institute. July 2002.

- Applicable output: *Associated level of value for consumer*
- Use of output: *Assign a monetary value or estimated market size to proposition*

The availability of convenient charging locations in frequented parking lots is an added value to potential PHEV owners who plan to plug in away from home on a regular basis. Such a convenience may convince consumers to pay a premium to have access to this. The project team is evaluating consumer preference survey data available from several potential resources, including UMTRI, UC Davis, and NREL, that demonstrates the percentage of individuals that would be willing to pay a cost premium for these conveniences, and, if so, the amount of extra money they are willing to spend to have them. Sentech will work with these organizations to obtain this specific data set and estimate its average quantitative value or estimated market size. Some benefits from convenient charging locations are expected to overlap with those from Opportunistic Charging described in 3.1.3. since consumers would be able to charge at these convenient locations at any time of the day.

3.1.6. Battery recycling credit
- Required data and/or model(s): *Second Use Battery Study*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Estimated salvage value of battery*
- Use of output: *Establish recycling credit to consumer*

A recycling credit will most likely be available at the end of a PHEV battery's useful life for vehicle applications; therefore, vehicle owners will recuperate a percentage of the PHEV's initial price premium. Battery recycling also benefits utilities and other entities that can obtain these used batteries at a discounted price for use in stationary applications. In order to assign a standard credit for recycled batteries, the estimated salvage value must be determined. Sentech will draw from the SNL/Sentech "Technical and Economic Feasibility of Applying Used EV Batteries in Stationary Applications" study to assess this value. Necessary updates and revisions will be made to account for any significant economic or technical changes that have occurred since its publication in 2003.

3.1.7. Recognition of "social" responsibility
- Required data and/or model(s): *Consumer Preference Data*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Associated level of value for consumer*
- Use of output: *Assign a monetary value or estimated market size to proposition*

Many consumers take pride in contributing to environmental and national goals (e.g., reduced emissions, oil independence), and they are often willing to pay premiums to use socially responsible products, including PHEVs, to help "do their part." Other consumers find value in the esteem received by owning such products and they may feel that a price premium is worth the level of admiration gained from their use. The project team is evaluating consumer preference survey data available from several potential

resources, including UMTRI, UC Davis, and NREL, that demonstrates the percentage of individuals that would be willing to pay a cost premium for these conveniences, and, if so, the amount of extra money they are willing to spend to have them. Sentech will work with these organizations to obtain this specific data set and estimate its average quantitative value or estimated market size.

3.2. *Societal Benefits*

3.2.1. <u>Reduced petroleum imports</u>
- Required data and/or model(s): *PSAT; southern California driving data*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *Reduction in petroleum use per vehicle*
- Use of output: *Address national strategic goals*

Since no increase in utility petroleum imports is expected, a reduction in petroleum imports will be primarily a result of a greater portion of liquid fuel being composed of renewable domestic resources and reduction in petroleum use per vehicle. In accordance with The President's Biofuels Initiative, DOE's goals require displacing 30 percent of transportation fuel consumed with renewable liquid fuels (biofuels) by 2030, thereby accounting for a fraction of petroleum imports. As vehicle fuel consumption is directly related to petroleum imports, the PSAT vehicle modeling tool is used along with California driving data to determine the reduction in fuel consumption on a per vehicle basis, providing a secondary method of calculating fuel cost savings. For the purposes of this study, it is presumed that 60% of the fuel saved would have been produced from imported petroleum.

3.2.2. <u>Emissions reduction</u>
- Required data and/or model(s): *GREET*
- Lead investigator(s): *Sentech, Inc.*
- Applicable output: *"Well-to-Pump" and "Pump-to-Wheel" GHG emissions (with and without PHEV fleet), and (to some extent) comparison of tailpipe emissions between conventional and PHEV vehicles*
- Use of output: *To quantify reduction in emissions*

PHEVs have the potential to reduce GHG and tailpipe emissions when compared to conventional vehicles, but much of the benefit will depend on many factors, including the mix of electric power generation and the duty cycles of the gasoline (or diesel) engines versus the electric motive power of the vehicles. For example, if all electricity were produced by nuclear power, then GHG emissions would be near zero from the electric drive portion of the vehicle's duty cycle. If, however, the electricity generation were all from coal-fired plants, the result would be much different.

The GREET model will be used to assess these subtleties and more. PHEVs built in 2030 are assumed to meet super ultra low emission vehicle (SULEV) standards; thus one could assume that tailpipe emissions will be at those levels. The GREET model can estimate vehicle emissions, but, in a case as complex as a PHEV, those estimates might

be suspect and would at least be subject to many assumptions. GHG emissions estimates will be more certain, and many different scenarios of PHEV penetration into the market, electric generation mix, and vehicle power plant duty cycles can be exercised.

3.3. Utility Benefits

3.3.1. Responsive load - V2B capability
- Required data and/or model(s): *California office building load profile from California Energy Commission and ASHRAE Advanced Energy Design Guide for Small Office Buildings (southern California climate), PHEV charge/discharge cycles*
- Lead investigator(s): *Sentech, Inc.; ORNL*
- Applicable output: *Reduced commercial building billing demand charge or "time of use"-based electric billing*
- Use of output: *Assign a monetary value to proposition*

It is assumed that commercial V2B will utilize commuter vehicles driven to urban areas, to reduce billing demand for office buildings. The charge/discharge cycle of a typical PHEV will 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 (e.g., SCE's Critical Peak Pricing (CPP) program) will be calculated from published California utility rate schedules, escalated to expected 2030 levels. It is expected that the regular V2B charging and discharging will be fairly shallow (not a full discharge). Responsive load operation, as under CPP, will occur rarely. The benefit of responsive load to utilities overlaps with the benefit to commercial business owners described in 3.4.3.

3.3.2. Increased use of renewable energy in generation mix
- Required data and/or model(s): *ORCED; MAPS*
- Lead investigator(s): *ORNL; GE Global Research*
- Applicable output: *Determine if higher off-peak loads reduce renewable energy curtailment*
- Use of output: *Determine if PHEVs can help meet RPS*

Elevated penetration of renewable energy resources in the 2030 timeframe will be evaluated in concert with the presence of PHEVs as loads. The study will look at hourly load profile data, PHEV recharge profiles, and typical renewable energy production characteristics. The study will look for obvious interactions between semi-dispatchable PHEV recharge loads and the characteristics of semi-volatile renewable energy production. The operational issues of renewable curtailment during periods of light load will be analyzed. This study begins with pre-existing database for the CAISO regional grid with known operating practices, thus providing an accurate and realistic view of renewable energy curtailment and the effects of dispatching PHEV loads. The output of

this study will impact the assessment of PHEVs' synergies with the future grid, and its generation emissions, energy costs, and stability margins.

California's RPS is likely to increase to 30% by 2030. It will be difficult for utilities to meet this, as the largest available renewable energy resource, wind, is strongest at night when there is not enough load to support all of it. To meet the RPS, utilities may have to turn to higher cost sources (e.g., photovoltaic) or add fixed energy storage (such as batteries). These additional costs per kWh of renewable energy to meet the RPS can be compared to PHEV cost premiums.

3.3.3. Carbon "tax" equivalent
- Required data and/or model(s): *Carbon emissions from GREET*
- Lead investigator(s): *Sentech, Inc.; ORNL; GE Global Research*
- Applicable output: *Change in fuel price and electricity price*
- Use of output: *Calculate PHEV and conventional vehicle operating costs*

If a carbon tax were to be instituted in the future, PHEV owners would benefit from greater savings relative to conventional vehicle owners since they consume a smaller overall volume of taxable fuel. This may be partially offset by the same carbon tax applied to electric rates. CO_2 emissions will be calculated with GREET, and the MBM will use this to calculate the change in vehicle operating cost.

3.3.4. Utility cost savings (capital or production) in $/kWh for serving PHEVs
- Required data and/or model(s): *MAPS; ORCED*
- Lead investigator(s): *ORNL; GE Global Research*
- Applicable output: *Change in cost of electricity for CAISO*
- Use of output: *Quantify PHEV operating cost savings*

Elevated penetration of PHEVs in the 2030 timeframe will be evaluated in concert with their effect on regional energy production costs. The study will look for obvious interactions between the semi-dispatchable PHEV recharge loads and the daily operational characteristics of a regional grid. The operational issues of renewable curtailment, economic dispatch of generation assets, and loading of generation assets will be analyzed. This study begins with pre-existing databases and simulation models for the CAISO regional grid with known operating practices, thus, providing an accurate and realistic view of PHEV impacts. The output of this study will give an assessment of PHEVs' impact on energy pricing ($/kWh) in a sample regional grid.

3.3.5. Time dependent electricity pricing for PHEV owners
- Required data and/or model(s): *Estimated time differentiated electric rates*
- Lead investigator(s): *Sentech, Inc.; ORNL*
- Applicable output: *Cost to charge PHEV*
- Use of output: *Assign a monetary value to proposition*

It is generally desirable that PHEVs be charged at night, during times of low production costs for electricity and light grid loading. Residential time of use rates or special PHEV off-peak rates will be employed to provide an incentive for PHEV owners to delay re-

charging until then. Required data includes the current pricing for electric vehicles that local utilities offer and their other residential rate structures. The relative costs of on-peak and off-peak versus their average will give an understanding of their non-energy cost additions. The other data needed will be the output of the ORCED model to find the expected cost of power needed to provide power to PHEVs at different time periods. Results from this analysis will help determine the expected cost structure for charging a PHEV throughout the day. A monetary value will be assigned accordingly.

3.4   Commercial Building Owner Benefits

3.4.1.   Emergency back-up power for commercial facility (commercial V2B)
   - Required data and/or model(s): *Published reports of costs of outages*
   - Lead investigator(s): *Sentech, Inc.; ORNL*
   - Applicable output: *Value of backup power*
   - Use of output: *Assign a monetary value to proposition*

Loss of power has different cost impacts on different types of customers. Residential customers for the most part see it as an inconvenience but do not place monetary values on the lost load. Commercial customers are more likely to see a quantitative impact, be it lost sales, productivity, or inventory. Cost studies have been conducted on different commercial market segments. Those with the highest self-perceived costs are likely to install emergency generation for critical loads. Rather than install a dedicated generator, some may choose to use their own fleet or employees' PHEVs. The value will be based on the potential losses, less the cost of adding the capability for connecting to the PHEVs.

3.4.2.   Responsive load – utility control of charger
   - Required data and/or model(s): *Analysis of utility load profiles; GE Global Research and OSU-CAR battery model*
   - Lead investigator(s): *Sentech, Inc.; ORNL*
   - Applicable output: *Determine what must be done to prevent spot / needle peak loads*
   - Use of output: *To modify load curve used for MAPS and ORCED*

The recharge process of PHEVs in the 2030 timeframe will be studied with respect to its impact on daily load profiles. The study will qualify the technologies needed to prevent PHEVs' recharging causing secondary or local peaks. This study requires some historical data of load profile ramp rates and spot electricity prices. A basic statistical simulation of PHEV recharge behavior is also core to the study. The output of this study will give a range of possible PHEV recharge load profiles vs. technology penetration to be used by the production model tools (ORCED, MAPS).

3.4.3.   Reduced billing demand for commercial building (commercial V2B)
   - Required data and/or model(s): *Typical California commercial customer load profile*
   - Lead investigator(s): *Sentech, Inc.; ORNL*

- Applicable output: *Reduced commercial building billing demand charge*
- Use of output: *Assign a monetary value to proposition*

Commercial building owners can use PHEVs parked in their lots to reduce billing demand. The required data needed to determine this benefit is the rate structure for commercial customers and typical commercial customer load profiles in southern California. PHEV charging in the morning and discharging to reduce the overall peak demand on the building should allow the commercial customer to reduce their demand charge for the month or season. A trade-off between how often the batteries are called upon and the savings from peak reduction will exist. There may be a spike in demand that a single use of batteries could alleviate, or there may be a relatively common peak load that would require frequent use of the batteries to reduce. The costs and benefits associated with billing demand will depend on factors such as the premium paid to vehicle owners, the frequency of discharge, the load shape for the building, and the rate structure of the utility. This benefit to commercial customers overlaps with the V2B benefits to utilities described in 3.3.1.

4. ROLE OF STAKEHOLDERS

Participation of stakeholders from all aspects of the PHEV industry is critical to achieving a successful and sustainable PHEV market. Since the Phase 1 case study simply represents the "baseline" deployment scenario for PHEVs, a minimal number of stakeholders are present. However, more third parties are expected to be added as business models become more complex throughout Phase 2 case studies. The roles of stakeholders for the Phase 1 case study are briefly defined below.

4.1. PHEV Owners

To realize operating cost savings, PHEV owners are expected to plug in at every convenient opportunity whether at work or home. Since most PHEV owners will be charging their vehicles during off-peak hours, it is also anticipated that most will depart for work with a fully charged battery. PHEV owners must be educated on how to maximize benefits and savings by preferentially charging during off peak hours.

4.2. Utilities

Utilities, including distribution systems, generators, ISOs, aggregators, or RTOs, have a large role in Phase 1. Utilities may be expected to set pricing that enhances the benefits of PHEVs. They may also have the ability to control or override when a PHEV can draw electricity from the grid for charging purposes to prevent local overloads or secondary peaks.

4.3. Facility Owners

The V2B applications being investigated in this case study can help facility owners avoid electricity premiums, resulting in significant annual energy savings. Therefore, facility owners in the southern California region are expected to provide V2B infrastructure to residents or employees by 2030. A small percentage of PHEV owners will find the benefits of this sufficient that they will be willing to allow their vehicles to be charged and discharged in the parking lot. Owners will be guaranteed a minimum SOC in the evening when they leave.

4.4. Financing Institutions

No financing institutions have been included in the Phase 1 case study. However, anticipated battery leasing models for Phase 2 will likely require the addition of such institutions. It should be noted that participants of the December Workshop pointed out that the cost of money is roughly equal for all businesses, and no obvious advantage for a third party owner exists. To be advantageous, third party ownership must be combined with other value attributes to establish a viable battery ownership business model.

4.5. Other Third Parties

No additional third parties have been included in the Phase 1 case study. However, the anticipated integration of V2G applications and battery leasing models for Phase 2 will likely require the addition of other entities.

5. PHASE 1 STATUS

Phase 1, Task 3 has been completed, and this document represents its corresponding deliverable. As shown in the Phase 1 timeline below, Task 3 also includes a Go / No-Go Feasibility Milestone. After being granted a "Go" by DOE, the project team has moved forward with the Phase 1 case study analysis, concluding that the available simulation models are adequate to perform evaluation in Task 4.

Phase 1, Task 4 analysis is currently underway. An interim report on the evaluation of Scenario #1 will be submitted in June 2008. This report will describe the conditions under which the value to the PHEV owner will justify the premium cost or investment. The resulting changes in load profile, production costs, fuel mix, emissions, reliability, and organization-specific economics will also be discussed. The combination of capital costs, operating costs, regulatory changes, etc., required to make PHEV purchases financially attractive will be documented. In addition, the sensitivities to these parameters will be provided. A qualitative risk analysis has also been planned for Phase 2. Based on the Interim Report conclusions, a third Go / No-Go Decision Milestone will take place. If granted a "Go" by DOE, the project team will proceed with Phase 2 operations.

PHASE 1

Task 1 — Identify Potential VA Propositions — ◇ *Workshop Report*

Task 2 — *Down-select* — ◆ — ◇ *Case Study Selection Report* — Select (≥3) VA Propositions

Task 3 — *Go/no-go feasibility* — ◆ — ◇ *Report on Recommended Evaluation Procedure* — Technical Req.'s (Scenario #1)

Task 4 — ◆ *Go/No go Phase 2* — ◇ *Interim Report* — Scenario Evaluation (Scenario #1)

Sep 07 Oct 07 Nov 07 Dec 07 Jan 08 Feb 08 Mar 08 Apr 08 May 08 Jun 08 Jul 08 Aug 08