SENTECH, INC.

Plug-In Hybrid Electric Vehicle Value Proposition Study

Phase 1, Task 2:

Select Value Propositions / Business Model for Further Study

April 2008

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INTRODUCTION

Recap of Task 1 Activities

The Plug-In Hybrid Electric Vehicle (PHEV) Value Propositions Workshop held in Washington, D.C. in December 2007 served as the Task 1 Milestone for this study. Feedback from all five Workshop breakout sessions has been documented in a Workshop Summary Report, which can be found at www.sentech.org/phev. In this report, the project team compiled and presented a comprehensive list of potential value propositions that would later serve as a "grab bag" of business model components in Task 2.

After convening with the Guidance and Evaluation Committee and other PHEV stakeholders during the Workshop, several improvements to the technical approach were identified and incorporated into the project plan to present a more realistic and accurate case study and evaluation. The assumptions and modifications that will have the greatest impact on the case study selection process in Task 2 are described in more detail in this deliverable.

Current Task at Hand

The objective of Task 2 is to identify the combination of value propositions that is believed to be achievable by 2030 and collectively hold promise for a sustainable PHEV market by 2030. This deliverable outlines what the project team (with input from the Committee) has defined as its primary scenario to be tested in depth for the remainder of Phase 1. Plans for the second and third highest priority/probability business scenarios are also described in this deliverable as proposed follow up case studies in Phase 2. As part of each case study description, the proposed utility system (or subsystem), PHEV market segment, and facilities/buildings are defined.

PHASE 1 CASE STUDY SELECTION

Summary of Selection

As a result of Workshop feedback, the project team has designed the Phase 1 case study to represent the "baseline" PHEV fleet of 2030 from which Phase 2 case studies can later build upon. The Phase 1 "baseline" scenario plans to include the following value propositions:

- Vehicle ownership benefits
    - Reduced vehicle operating cost (with GPS-enabled fuel optimization dispatch)
    - Tailgating/camping, limited household appliance backup (i.e., residential "vehicle to building" (V2B)) capabilities
    - "Opportunistic" charging of PHEV at the end of a trip
    - Reduced vehicle maintenance costs
    - Ability to fuel PHEV from any outlet for portion of fleet
    - Convenient charging stations (e.g., at airports, municipalities, etc.)
    - Battery recycling credits
    - Recognition for social responsibility (psychological rewards)
- Societal benefits

    - Reduced petroleum imports (both economic and geopolitical benefits)
    - Emissions reduction
    - Increased use of renewables in generation mix
- Commercial building owner benefits
    - Commercial V2B capability for portion of PHEV fleet to reduce building billing demand, respond to dynamic pricing, or for critical load back-up
- Transmission and distribution system benefits
    - Limited “vehicle to grid” (V2G) functions to provide reserve capacity or other ancillary services
- Utility benefits
    - Responsive load – utility control of charger scheduling
    - Increased use of renewables in generation mix
    - Carbon “tax” equivalent
    - Utility cost savings (capital or production) in $/kWh for serving PHEVs
    - Time dependent electricity pricing for PHEV owners

The project team has chosen southern California as the Phase 1 case study location, because the economic, environmental, social, and regulatory conditions are conducive to the advantages of PHEVs. As regional factors will affect outcomes, PHEVs may be successful in California but less so elsewhere due to differences in utility structure, climate and other factors. Assuming steady growth of PHEV sales and component production capacity over the next two decades, PHEVs in this area are postulated to comprise approximately 10% of the area’s private vehicles (about 1,000,000 vehicles) in 2030. PHEV-30 models will be analyzed in this study, and they will contain an appropriately sized (likely 10 kWh) lithium-ion battery, which when charged at 120 volts will have an initial load of 1.5 kW. They 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. More specific PHEV vehicle modeling parameters and fleet characteristics of 2030 are described later in the “Phase 1 Case Study Description” and “Vehicle Modeling Parameters” sections.

Assumptions

The case studies to be examined throughout this study will require projections spanning the next two decades. Since the world of 2030 is anticipated to undergo many economic and technological transitions during this time frame, several assumptions must first be made before realistic business scenarios can be constructed. To assist in defining these assumptions, the project team drew from the knowledge of Workshop participants of Breakout Session 5, composed of experts from all aspects associated with the PHEV industry. Breakout Session 5 participants were tasked with creating a “Consensus Vision for 2030-2040” that forecasted regulatory changes, technology breakthroughs, infrastructure characteristics, nature of fuel supply, and more, spanning the next three decades. Below is a list of factors that Breakout Session 5 participants believe will have the most significant impacts on the market acceptance of PHEVs:

- To be sustainable, a PHEV fleet must comprise 5-10% of new vehicles sold annually. Participants agree that this volume is not realistically achievable by 2020, and an extension to 2030 has been made.
- Corporate Average Fuel Economy (CAFÉ) standards will be greater than 35 miles per gallon in 2030.
- Oil cost will continue to increase to over $150 per barrel in 2030. Cost of other fuels, including electricity derived from petroleum or natural gas, will also rise significantly.[1]
- 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 may likely be adopted by 2030, including supporting infrastructure. However, the broad implementation of V2G applications is believed to be unlikely by 2030.
- Most first generation PHEV chargers will only be capable of charging at 120 volts. Over time, dual voltage chargers will be introduced to accommodate quick charging, V2G and V2B applications.
- The majority of the PHEV fleet will be capable of only unidirectional electricity flow by 2030 though with limited power available for off-road or emergency use.
- Battery recycling capabilities will be in place due to regulations.
- Both NiMH and lithium-ion batteries will power the PHEV fleet in 2030. However, all new PHEVs sold after 2030 are assumed to have lithium-ion batteries.
- PHEVs will offer 70% higher fuel economy relative to conventional drive vehicles in 2030 with approximately 30 mile all-electric range equivalent.
- A $6,000-9,000 price premium will exist for PHEVs relative to conventional drive vehicles.
- Advanced metering and roaming will be available nationwide by 2030.
- From an accounting standpoint, PHEVs will be separately tracked and billed (a “virtual” meter), not to be confused with the traditional model of a separately installed billing meter.

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 advanced and reliable enough to simply turn the wheels. This is critical because the primary value expected of a PHEV is the reduced operating costs to the owner. Accurate assessment of additional value, such as ancillary services and load response, V2G operations or third party ownership of batteries, requires detailed modeling of vehicle performance, electricity costs, and market size. These in turn are dependent on consistent assumptions of the

[1] Energy Information Administration (EIA) fuel price projections will be 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 EIA price projections have already been shown to be too low, revised fuel price projections will also be used to evaluate the value propositions. These revised price levels will be consistent with the long-term planning assumptions made by the State and utilities chosen for the Phase 1 case study.

generation mix and dispatch parameters of the power systems and of the PHEV driving and battery charge/discharge profiles. The Committee agrees that the magnitude and scope of such advanced value propositions can not be evaluated accurately until the basic "batteries to wheels" scenario is adequately specified.

Therefore, the project team has decided to estimate and model the PHEV "baseline" fleet of 2030 for Phase 1 of this study in order to focus on the primary goal of demonstrating lower operating costs for the driver. In Phase 2, the Phase 1 scenario will be modified to enhance the expected value of the lower vehicle fuel costs with the addition of value propositions and business models whose parameters are dependent on the power system and vehicle operating characteristics of the Phase 1 "baseline" scenario.

Since the objective of Phase 1 is to establish a baseline scenario, the project team will not investigate the business concept of a third party owning and leasing batteries to PHEV customers, which is appealing to vehicle manufacturers and utilities for various reasons. The simulation of these third party business strategies may require the construction of complex business sub-models that include a mix of leasing, refurbishing, reusing, and selling strategies. However, the financial and technical requirements needed to build such business sub-models cannot be known until the "basic" PHEV economics (e.g., PHEV driving characteristics, battery charge/discharge cycles) are determined in Phase 1 analysis. Therefore, third party ownership business sub-models will be pursued in parallel to the Phase 1 case study in order to conduct a comprehensive analysis later in Phase 2.

For similar purposes, the Phase 1 case study will take only a brief glimpse at limited V2G functions capable of providing some reserve capacity or other basic ancillary services, but the project team will withhold the full scale implementation of V2G until Phase 2 case studies. The decision to investigate only a small portion of V2G functions in Phase 1 is 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 take place. Therefore, more advanced V2G value propositions will be examined in Phase 2 once data on the power system, ancillary services market, and vehicle characteristics have been collected in Phase 1 analysis.

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.

Available Value Propositions

The following page shows the complete list of value propositions generated at the Workshop. The project team selected from this list of business model components to construct case studies for both Phases 1 and 2. Each value proposition has been categorized by a value estimation method (see key) that correlates to the type of model or data analysis anticipated for use in Task 3.

Table 1: *List of value propositions generated at the Workshop*

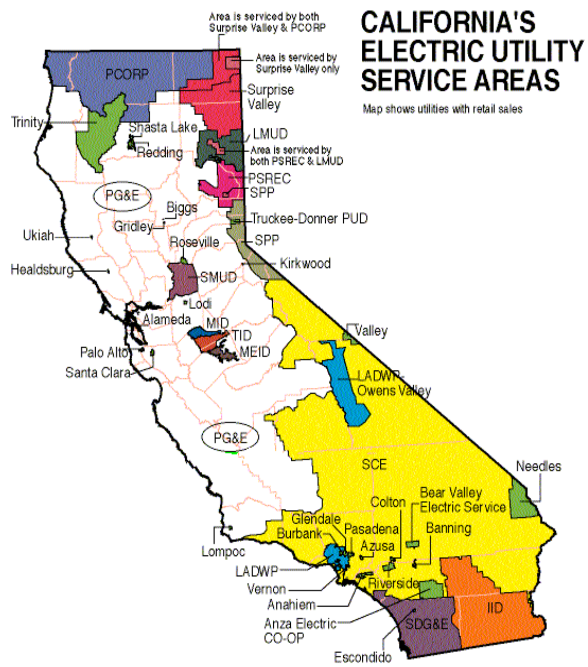
VALUE PROPOSITION	VALUE ESTIMATION METHOD	INCLUDED IN PHASE 1?
Applicable to PHEVs with Unidirectional, V2G, or V2B Capabilities		
Fuel cost savings (with GPS-enabled fuel optimization dispatch)	MV, MUPC	✓
Reduced vehicle maintenance costs	MV, CP	✓
Emissions reduction	MVE, MUPC, MUE	✓
Increased use of renewable energy in generation mix	MUPC, MV, GP	✓
Reduced petroleum imports	MUPC, MV, GP	✓
Carbon “tax” equivalent	GP	✓
Opportunistic charging / ability to refuel from any outlet for portion of fleet	CP	✓
Time dependent electricity pricing for PHEV owners	CP, MV	✓
Recognition of “social” responsibility	CP	✓
Tailgate/camping, limited household appliance backup (residential V2B) capabilities	CP	✓
Utility cost savings (capital or production) in $/kWh for serving PHEVs	MUPC	✓
Responsive load – utility control of charger	MUPC	✓
Increased use of renewable energy in home	MF, CP	
Convenient charging locations (e.g., at airports, municipalities, etc.)	CP	✓
Battery recycling credit	GP	✓
Applicable to PHEVs with V2G or V2B Capabilities Only		
Reduced billing demand for commercial building (commercial V2B)	MF, MB	✓
Emergency back-up power for commercial facility (commercial V2B)	RS, CP	✓
Responsive load - V2B capability	MUPC, MF, MB	✓
Enhanced responsive load - V2G capability	MUPC, MF, MB	
Ancillary services – distribution system voltage support (V2G)	MUDS, MB	
Ancillary services – bulk power system (V2G)		Only estimate marginal value in Phase 1 through sensitivity studies
➢ Spinning reserves	MUPC, MB	
➢ Regulation	MUDY, MB	
➢ Volt/var support	MUDY, MB	
Increased use of renewable energy through system regulation	MUPC, MUDY	
Coordination of rail mass transit and PHEVs in parking lot	MF, MUDS, MB	
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	GP	
State government incentives/programs/tax credits	GP	
HOV access, reduced tolls, city center or restricted street access	CP, GP	
Preferred parking	CP	

CP: *Consumer preference data/studies*
GP: *Valuing government policy or incentives*
MB: *Battery lifetime modeling*
MF: *Facility modeling/bill analysis*
MUDS: *Distribution system modeling*
MUDY*: Modeling utility system dynamics or load flow*
MUE: *Utility emissions modeling*
MUPC: *Utility production and capital cost modeling*
MV: *Vehicle performance modeling*
MVE: *Vehicle emissions modeling*
RS: *Published consumer reliability studies on cost of service interruptions*

Phase 1 Case Study Description

The project team has decided to use 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 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.

The southern California region includes numerous utilities, 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 significant determinants of the performance of the California Power Pool.



Source: Lassen Municipal Utility District (1996)

The southern California area has about 10,000,000 private vehicles. Assuming 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 10% of the area's private vehicles (about 1,000,000 vehicles) in 2030. PHEV-30 models will be analyzed in this study, and they will contain an appropriately sized (likely 10 kWh) lithium-ion battery, which when charged at 120 volts will have an initial load of 1.5 kW. They 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 be equipped only for charging at 120 volts, which restricts most PHEVs from V2G or commercial V2B capability. Still, PHEVs with only a 120 volt 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 120 volt / 240 volt chargers and V2B or V2G capability. All new PHEV models sold in 2030 and beyond will have either a dual charger (both 120 volt and 240 volt capabilities) or a 240 volt charger. Hence, 120 volt-only chargers are expected to be phased out by 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. These "opportunistic" charges are expected to occur for approximately 5% of post-morning commutes and 15% of post-evening commutes. 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) that would avoid high needle peaks on the distribution system that would occur if the chargers were to all begin charging simultaneously.

The majority of the PHEV owners will choose to only charge during off-peak hours in their garage. However, about 40% (4% of the total vehicle fleet) will charge during standard work hours at charger-equipped parking facilities. Some of these parking facilities will be able to act as aggregators providing responsive loads and some degree of ancillary services in regulating the charging for 120 volt PHEVs. 240 volt PHEVs will be able to provide full V2G and V2B functionality.

A small portion (approximately 10%) of the 2030 PHEV fleet and all new PHEVs sold in 2030 will have commercial V2B capability, which requires 240 volt 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 GPS systems capable of optimizing blended fuel economy by remembering recurring trips or analyzing driver-entered destinations in combination with the drive train controller (dispatch of the battery discharge and use of on-board fuel). These fuel savings accrued by the owner will be analyzed in Phase 1.

To validate and revise the specifics of this case study, members of the project team have met with representatives of SCE, including a member of the Guidance and

Evaluation Committee. SCE is currently working with Ford Motor Company on a large PHEV development, evaluation, and performance monitoring project. For example, confirmation of commuter driving distances in the Los Angeles metropolitan area will be needed to ensure that a PHEV with a battery capacity of 10 kWh is appropriate for the PHEV model.

The current southern California utilities' power systems and CAISO will provide the initial data for modeling the 2030 power system. The load forecasts, fuel price forecasts, and generation expansion plans for southern California will be used to estimate the characteristics of the 2030 power system. However, the forecasted generation mix for 2030 will be modified to incorporate a 30% renewable portfolio standard and any expected improvements to power generation technologies (efficiencies and emissions characteristics). The EIA Annual Energy Outlook values and the predicted Workshop values shown in Table 2 will also be used to simulate the effects of a carbon "tax"; fluctuating oil, gasoline, natural gas, and electricity prices; and increased CAFÉ standards. As time permits, a broader sensitivity range (seen in Table 2) will be investigated for each variable.

Table 2: *Comparison of EIA projections and workshop predictions for 2030, each with a designated sensitivity range.*

	EIA Projections	**Workshop Predictions**	**Sensitivity Range**
Carbon "Tax" (2006 \$ / ton of CO_2)	N/A	30-50	0 - 150
Oil Price[2] (2006 \$ / barrel)	70.45	150	70 - 450
Gasoline Price (2006 cents / gal)	244.6	N/A	200 - 1000
CAFE Standard (mpg)	30.0 [3]	35	30 - 100
Electricity Rate[4] (2006 cents / kWh)	10.5	N/A	5 - 100 [5]
Natural Gas[6] (2006 \$ / thousand ft^3)	7.13	N/A	5 - 20

[2] Imported Low-Sulfur Light Crude Oil
[3] EIA's Estimated "Average Fuel Economy" for 2030
[4] End-Use Prices – Residential
[5] Range includes a mixture of off-peak and on-peak rates
[6] Delivered Prices – Electric Power

VEHICLE MODELING PARAMETERS

Table 3 shows a breakdown of the established vehicle parameters required for modeling simulations used in this study. For the initial "baseline" scenario in Phase 1, the project team will be evaluating the Mid-size PHEV-30 design. (The performance simulation analyses will determine the blended mileage performance to be expected from the PHEV-30 design.) An HEV and conventional vehicle with comparable performance will be modeled and simulated as a "baseline" reference. As time and funding permits, the Crossover and Sports Utility Vehicle (SUV) PHEV models will also be investigated.

***Table 3:** Required Vehicle Modeling Parameters for PHEV-30*

Vehicle Class	**Mid-size**	**Crossover**	**SUV**
Glider Mass (kg)[7]	693	812	882
Frontal Area (m^2)	2.27	2.76	2.97
Drag Coefficient	0.24	0.32	0.37
Electrical Accessory Load (W)	260	260	260
A/C Load (W)[8]	1088	1088	1344
Engine Specific Power (W/kg)	920	920	920
Engine Peak Efficiency (%)	38.5	38.5	38.5
Battery Type	Li-ion	Li-ion	Li-ion
Battery Energy (kWh)[9]	10-15	12-17	14-18
Battery Power (kW)[10]	40	55	55
Motor Specific Power (kW/kg)	1.4	1.4	1.4
Power Electronic Specific Power (kW/kg)	12	12	12
Electric Drive Peak Efficiency (%)	92	92	92

[7] 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

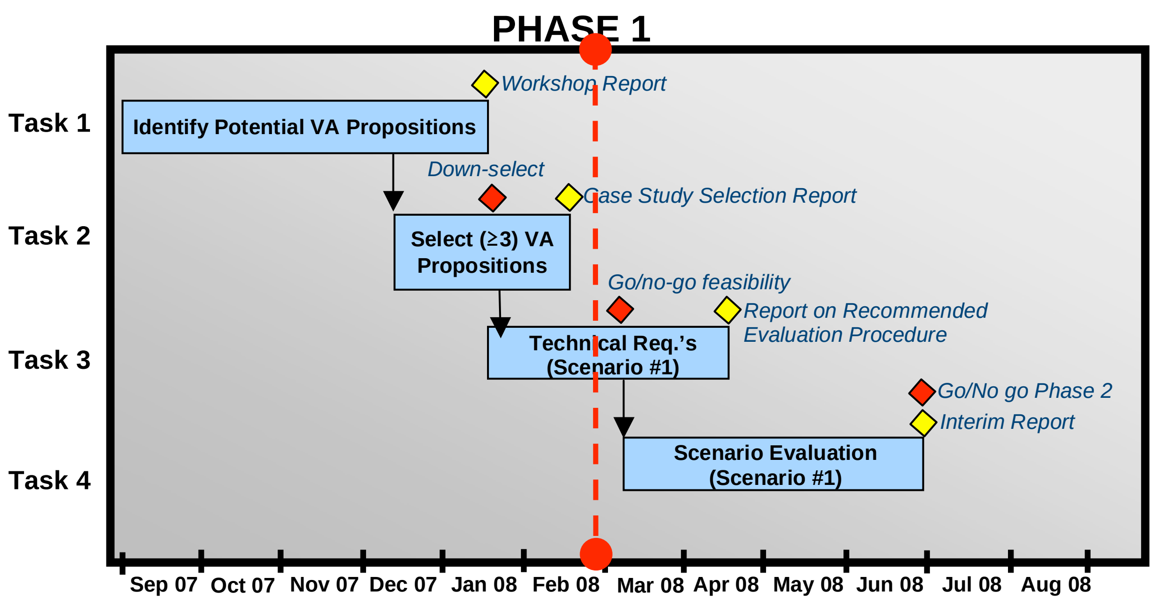
[8] Data provided by John Rugh (NREL) - assumed 50% of the time when the A/C is on, the vehicle is undergoing a cooldown from a solar soak when the initial interior air and mass will be 60-80°C. The other 50% is steady state operation. The humidity was as 65% during the ARCRP tests.

[9] Some concern has been shown that 10kWh may not be sufficient for a AER of 30

[10] 40kW for 10sec at 25% SOC, assumes blended control strategy

PHASE 1 STATUS

As displayed below, the project team has reached Task 2's milestone, and the corresponding deliverable has been completed. The technical requirements (e.g., data, models, and analysis procedures) for assessing the initial case study are currently being defined as part of Task 3, and the recommended evaluation procedure will be presented in the next status report. At the close of Task 3, the project team will reach its first Go/No-Go decision milestone, which will determine if the developed simulation models will be adequate to perform the case study evaluation.



PHASE 2 CASE STUDY PLANS

Since southern California likely displays the "best case" scenario for the introduction of PHEVs, Phase 2 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 Phase 2 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 reduced CO_2 emissions. Modifications to the value propositions analyzed in the Phase 1 scenario (financial and technical characteristics and/or number of vehicles) will be made based on the results of Phase 1 testing and review by DOE and the Guidance and Evaluation Committee. Phase 2 will also include the following anticipated additions to the existing "baseline" model:

- Advanced 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 during Phase 1 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 120-volt unidirectional capability only, or controlling individual charge and discharge of 240-volt 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).
- Business models for battery leasing, third party ownership, and battery buy-back/recycling programs, based on the financial and battery modeling outputs of Phase 1.

Assuming the project team is granted a "Go" after the Phase 1 interim report, Phase 2 will kick off with the identification of technical requirements and evaluation procedures needed to analyze the second and third case studies with the greatest promise of a viable PHEV market by 2030. As shown below, input from Phase 1 will be vital in several Phase 2 tasks.