



SENTECH, INC.

Plug-In Hybrid Electric Vehicle Value Proposition Study

Project Plan

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SENTECH, INC

EPRI



OAK
RIDGE
National Laboratory



PLUG-IN HYBRID VEHICLE AND ELECTRIC GRID VALUE PROPOSITION STUDY

PROJECT PLAN SUMMARY

SENTECH, INC., Oak Ridge National Laboratory (ORNL), General Electric Corporation (GE), and Electric Power Research Institute (EPRI) will conduct a study of the benefits, barriers, opportunities and challenges of grid-connected, plug-in hybrid electric vehicles (PHEV) to establish potential value propositions that will lead to commercially viable PHEVs. Each team member represents a critical element in the analysis of the value proposition. While there is significant overlap in the members' capabilities and the assignments that will be made within the project, the primary function of each member is as follows:

- ORNL – *Project manager* – ORNL will also provide regional utility and emissions modeling considering out-year generation mix. This study builds on the previously performed PHEV impact analysis of the Carolinas as well as studies for the Office of Electricity on the value of ancillary services to regional grids. ORNL will also provide conceptual designs of vehicle power electronics systems required to accomplish the scenarios to be studied.
- SENTECH, INC. – *Subcontract manager, vehicle modeling and simulation* – SENTECH, INC. will leverage currently funded projects in PHEV energy management strategy research and emissions analysis.
- GE – *Grid interface analysis, modeling and design* – GE will leverage work currently funded with the Office of Electricity and the private sector.
- EPRI – *Utility generation/interface expertise* – EPRI will leverage currently funded work on PHEV/grid impacts being performed for the utilities.

A Guidance & Evaluation Committee will also assist with the performance of this study. Several organizations are currently being considered for participation on this committee:

- California Energy Commission
- Duke Energy
- Edison Electric Institute
- Ford Motor Company
- General Motors
- Johnson Controls
- New York State Energy Research and Development Authority
- Public Service New Mexico
- Southern California Edison
- A123Systems
- Tennessee Valley Authority
- Toyota
- Auto Dealerships

BACKGROUND

The Office of Energy Efficiency and Renewable Energy has established a success indicator that, “By 2020, vehicles are available that double fuel economy at an

incremental cost that is paid back within three years through fuel cost savings.”¹ PHEVs are capable of achieving double the fuel economy; however, in the near term, the cost premium of a PHEV will likely exceed the fuel saved over a reasonable ownership period for the average driver. To achieve commercial viability, the PHEV must provide more value than fuel savings alone. The added value of PHEVs could accrue to the vehicle owner, utility, building (facility) owner, energy services company or load aggregator, and/or local or national government. To realize the full potential benefits of PHEVs, the vehicle must not only achieve certain cost and performance targets; the necessary grid interconnect infrastructure, institutional incentives and business opportunities, and tax or other regulatory incentives must also be in place.

A strategy that enables PHEVs to successfully penetrate the marketplace and operate in a manner that significantly reduces national consumption of petroleum must address the following:

- Vehicle capabilities
- Vehicle support infrastructure
- Target market segments for PHEVs
- Vehicle charge/discharge and operating schedules
- Utility system designs and operation procedures that take advantage of PHEVs as a resource – providing location-specific energy or dispatchable load
- Value propositions and business cases for vehicle owners as well as other institutions or entities
- Coordinated rebates, policies, and other incentives that support those value propositions

Specifying and evaluating a viable PHEV market scenario will require an imaginative and innovative approach that identifies all potential value added propositions for PHEVs and suggests how they might be integrated. The determination of true costs and benefits (and to whom they accrue) requires detailed technical and economic models of vehicles and charging infrastructure, electric utilities (distribution, transmission, and generation), facilities, communications systems, emissions, financing, and consumer purchasing. The scenario must also address the world of 2020 and beyond. For example, the value of PHEVs to the electric grid must be evaluated in terms of the generation mix and the targeted PHEV fleet of 2020 – not today’s. Nevertheless, the strategy to get there must start with the present and postulate an evolution of technical, economic, and regulatory developments that will result in a PHEV fleet-compatible electric grid in the future.

OBJECTIVE

The objective of this project is to identify and evaluate value-added propositions for PHEVs in order to develop viable strategies for achieving levels of PHEV penetration

¹ Department of Energy, *Office of Energy Efficiency and Renewable Energy Strategic Plan*. 2002. <http://www.nrel.gov/docs/fy03osti/32988.pdf>.

and appropriate operating strategies that will help achieve national goals of energy independence, energy security, robust infrastructure, environmental protection, and economic stimulation. The following strategies will be utilized:

- Incorporation of organizational arrangements and regulatory policies required to realize the most attractive value propositions
- Identification of the most advantageous markets for PHEVs for each value proposition
- Specification of the infrastructure needed to interconnect PHEVs to the grid on the distribution and building facility levels
- Definition of technical research and development activities for vehicles/batteries, building systems, communications and controls, and grid architecture and components

APPROACH

Overview

The technical approach to establish the value of the PHEV and/or its energy storage system to both the utility and the consumer under multiple scenarios is summarized below:

- Identify potential value propositions for PHEVs including operation and financing strategies, technical capabilities, and institutional actions or roles needed to implement them.
- Determine models and data required to evaluate the value propositions. Augment existing models or evaluation techniques as necessary.
- Apply the models to evaluate selected PHEV scenarios on a case study basis. (This includes identifying specific locales and market segments relevant to the value proposition being studied.)
- For economically attractive PHEV business cases, identify technical, regulatory, or economic requirements and any barriers that must be overcome. (This includes determining the requirements of the PHEV charging/grid interconnection infrastructure.)
- Identify physical, economic, and/or market characteristics that are determinants of the viability of a business case. These characteristics, together with the operating data (e.g., charge/discharge strategies, communications infrastructure, financing methods, utility load profiles, resulting emissions), will provide inputs to other Department of Energy (DOE) national or regional PHEV assessments.

Task Statement

This study will be divided into phases. Each phase will have a logical termination point and will include a go/no-go decision milestone.

Phase 1, Task 1: Identify and Characterize Potential Value-Added Propositions for PHEVs.

SENTECH, INC. will form an advisory committee of automotive, energy storage, utility and other experts that will periodically provide input and review progress of the team. SENTECH, INC. will also facilitate a workshop for the team participants, advisory committee and other stakeholders in order to establish a list of potential business models that provide additional value to the utility, the vehicle owner, or a third party. These models might examine the ownership of the energy storage system by a utility or financial institution or the possibility of a utility leasing or buying stored energy from the vehicle owner, etc.

Several options can be considered to increase PHEV value including:

- Access to HOV (high-occupancy-vehicle) lanes
- Preferred parking (possibly with renewable energy recharging available)
- Access to all-electric inner city zones (presuming they are implemented)
- Emergency power for the home
- Utilization of some of the energy stored in the PHEV batteries for load leveling, congestion relief, or as an emergency power source
- Ownership or leasing of batteries by the utility or a third party rather than by the consumer
- Payment by the utility to the consumer for use of the vehicle's batteries for reliability or system economic purposes
- Use of stored energy in PHEVs parked at a facility (e.g., hospital, office complex, shopping center/mall) to augment local back-up power sources at the start of an outage with premium payments made to the owners of vehicles that provide support
- Use of "Smart Meter"-type communications and controls to enable the utility to charge and discharge PHEV batteries based on real-time marginal electricity costs or maximizing use of as-available renewable energy sources [The technology to accomplish this (or to facilitate the vehicle owner's ability to charge in multiple locations) already exists in electronic meters with remote reading and pre-pay capabilities.]
- Provision of ancillary services to the utility, including operating reserves, local reactive power (VAR) or voltage support, stability or Area Control Error (ACE) support, etc.

Phase 1, Task 1 Deliverable: Workshop report is due two and one half months after subcontract award.

Team Member Roles:

- SENTECH, INC.
 - Prepares presentations for and participates in kick-off meeting
 - Plans workshop logistics

- Assists in preparation for the workshop
- Participates in the workshop, provides facilitators and notetakers
- Prepares and edits workshop report
- GE
 - Selects one GE staff member to participate in Washington, DC value added workshop
 - Provides pre-workshop suggestions for value proposition (via telecom)
 - Participates in preliminary discussion of required models, data, and analytical procedures
 - Assists SENTECH, INC. in preparing presentation materials for the workshop
 - Provides input for workshop report
- EPRI
 - Selects one EPRI staff member to participate in Washington, DC value added workshop
 - Provides pre-workshop suggestions for value proposition
 - Provides preliminary estimates of required models, data, and analytical procedures
 - Provides input for workshop report
- Guidance & Evaluation Committee
 - Selects one or two committee members from each organization on the committee to participate in the value added workshop in Washington, DC
 - Provides input for workshop report

Phase 1, Task 2: Select Value Propositions/Business Cases for Further Study

The business models or value proposition scenarios will be prioritized and the highest priority model will be evaluated in Phase 1; the second and third highest priority models will be evaluated in Phase 2. (Additional models or variants of the first three models could be evaluated in subsequent phases of this study.) Case study locations for each of the three scenarios will be selected: utility system (or subsystem), PHEV market segment, and facilities/buildings will be included.

Phase 1, Task 2 Deliverable: Case study selection report is due four months after subcontract award.

Milestone: Down-select to the three highest priority/probability business cases with one business case selected for continuation in Phase 1 and two business cases selected for evaluation in Phase 2.

Team Member Roles:

- SENTECH, INC.
 - Provides input to preliminary analysis of business models

- Provides input to selection of case study location, including assessment of available data
- Prepares and edits case study recommendation report

- GE
 - Provides input to preliminary analysis of business models
 - Provides input to selection of case study location, including assessment of available data
 - Reviews deliverable report

- EPRI
 - Provides input to preliminary prioritization of business models
 - Provides input to selection of case study location, including assessment of available data
 - Reviews deliverable report

- Guidance & Evaluation Committee
 - Provides input to preliminary analysis of business models
 - Provides input to selection of case study location
 - Reviews deliverable report

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

In Phase 1, one of the three high-priority business cases identified in Task 2 will be evaluated. This will include the determination of data, models, and analysis procedures required to evaluate this case study scenario. Existing models will be modified as needed to perform the analysis of the business proposition and establish relationships between costs and value to the respective owners. For some aspects, it may be necessary to develop new models to perform the analysis. The “models” will include technical and economic/financing assessments. The role of PHEV owners, utilities (distribution systems, generators, independent system operators, aggregators, or RTOs), facility owners, financing institutions, and other third parties will be defined.

To fully explore the functions and benefits of grid-coupled PHEV, the following elements must be addressed and will be contained in the approach described above:

- Full specification/delineation of potential PHEV-grid interconnection functions considered together with the associated vehicle owner/utility/facility manager* business cases and possible tariff structures or contracts

* For example, homeowners could use the PHEV for back-up power during an outage. PHEVs with sufficient fuel and charge that are “plugged in” at facility parking lots (hospitals, shopping malls, office buildings) could be utilized for an orderly shut-down of the facility (malls, offices) or to extend on-site emergency fuel supplies (hospital). The utility would pay the PHEV owner for the energy used and would, in turn, charge a premium to the facility owner making use of the emergency PHEV power.



- Specification of the PHEV charger and grid interconnection station including required ratings, communications, control, protection, and monitoring required to implement the functions of first item
- The company provision of the preliminary design of the hardware and power electronics at the vehicle level for the above
- Facility modeling to develop the control strategy that must be incorporated into the building energy management and control system in order to incorporate the use of PHEV for emergency power for facility support
- Grid modeling to develop a methodology to determine the system benefits and constraints of the functions in bullet #1
- Case study utility impact analysis to determine the changes in production costs and generation requirements for specific scenarios of PHEV penetration and use (This analysis may require the use of grid analysis tools such as DSS, MAPS™ and PSLF, as well as data from relevant utility studies of application of micro-grids, distributed generation, or renewable energy and storage, to develop the response requirements and value proposition/utility base cases for the PHEV-grid interconnection functions.)
- Specification of monitoring and control on-board the vehicle as necessary for the functions of bullet #1
- Development of a detailed battery charging model that can translate charge/discharge duty cycles into effects on battery efficiency, expected lifetime, and reliability (Batteries in particular represent an area where there are more unknowns than knowns. Optimistic and pessimistic lifetimes versus charge/discharge duty cycles will be evaluated, and a sensitivity analysis will be performed.)
- Vehicle modeling to identify changes in expected PHEV capabilities needed to implement the functions in #1 [Vehicle modeling is an essential element of this study and will be performed using analytical tools such as the DOE Powertrain Systems Analysis Toolkit (PSAT). PSAT will be used to predict the potential fuel economy benefits for the purposes of this research as well as the usable energy storage requirements for a variety of vehicle architectures and weight classes. Current work being performed in the area of PHEV energy storage requirements by the Energy Storage Technical Team and the USABC will be drawn upon. PSAT is a sophisticated vehicle level modeling tool developed using industry standard MATLAB/SIMULINK® software. It provides a sound basis for modeling advanced powertrains as well as powerful graphical user interfaces for post-processing of data. PSAT will be used to develop and identify reference PHEV vehicles and candidate PHEV control strategies for further investigation into grid usage impacts. New “operation” cycles will be developed that address both grid-connected charging (including charging efficiencies) and the prospects of vehicle-to-grid functionality.]
- Definition of power electronics requirements for a vehicle that could function as described in this project plan
- Establishment of vehicle battery requirements for the vehicle using PSAT
- Development of scenarios including the utilities’ islanding-related and protection/short circuit interconnection standards (IEEE 1547) (Where the PHEV

- might feed into the grid, either for utility or homeowner benefits, the interconnection hardware and monitoring/communications requirements of the PHEV and its charging station become more complex.)
- Vehicle population and distribution modeling to include vehicle location and state of charge as a function of time of day
 - Provision of the incremental change in utility emissions by the company using the ORCED Model
 - Incremental change in vehicle emissions using the MOVES and PSAT Models (MOVES is a model developed by EPA to calculate the impact of new technologies on vehicle emissions. MOVES includes the Argonne National Laboratory GREET model.)

Phase 1, Task 3 Deliverable: Seven months after the subcontract award, a report on the recommended evaluation procedure for Scenario #1 will be submitted that includes the following:

- Specification and business case description of potential PHEV-grid support functions
- Requirements for facility monitoring and control to incorporate PHEV support
- Procedure for determining the value proposition of PHEV utility or facility support functions and incremental changes in emissions

Milestone: Go/no-go decision - Simulation models are adequate to perform the business case scenario evaluation.

Team Member Roles:

- **SENTECH, INC.**
 - Participates in the development of an evaluation procedure for selected case(s) (Includes one meeting in Washington, DC)
 - Focuses on vehicle and emission model integration such as PSAT and MOVES
 - Develops overarching integration model
 - Directly develops new models and modifies existing models as required
- **GE**
 - Participates in the development of an evaluation procedure for selected case(s) (Includes one meeting in Washington, DC)
 - Develops a comprehensive scenario evaluation methodology and data
 - Focuses on how to use utility production model tools in the evaluation process
 - Focuses on integration of new or pre-existing models with other models used in the study
 - Sets up necessary cases, including limited data collection for pre-existing models



- Makes required changes to output processing to meet project needs for the evaluation procedure
- Assists in writing report on business case(s) evaluation procedure
- EPRI
 - Participates in the development of an evaluation procedure for selected case(s)
 - Develops plan to use EPRI's Distribution System Simulator (DSS)
 - Develops plan to integrate DSS with other models that will be used
 - Sets up necessary DSS cases, including data collection
 - Makes required changes to output processing to meet project needs for the evaluation procedure
 - Assists in writing report on business case(s) evaluation procedure
- Guidance & Evaluation Committee
 - Participates in the development of evaluation procedure for selected case(s) (Includes one meeting in Washington, DC)
 - Provides input for report on business case(s) evaluation procedure

Phase 1, Task 4: Scenario Evaluation

Scenario #1 will be analyzed and the conditions will be identified under which the value to the owner will justify the cost or investment. The resulting changes in load profile, production costs, fuel mix, emissions, reliability, and organization-specific economics will be discussed. For this scenario, 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. Probability/risk in achieving these levels will also be analyzed.

Phase 1, Task 4 Deliverable: Ten months after the subcontract award, an interim report on the evaluation of Scenario #1 will be submitted that includes the following:

- Revised (as necessary) specification and business case description of potential PHEV-grid support functions and conditions for a positive value proposition
- Functional specification of PHEV charging infrastructure
- Revised (as necessary) requirements for facility monitoring and control to incorporate PHEV support
- Revised (as necessary) procedure for determining the value proposition of PHEV utility or facility support functions and incremental changes in emissions
- List of potential changes to PHEV requirements or battery charging strategies necessary to support interactive grid-PHEV interface

Milestone: Go/no-go decision – Project results provide valuable insight and warrant proceeding with Phase 2.

Team Member Roles:

- **SENTECH, INC.**
 - Runs vehicle, emissions, and integration model
 - Participates in scenario evaluation (Includes one meeting in Washington, DC)
 - Prepares and edits interim report
- **GE**
 - Administers GE models as appropriate for the scenario evaluation
 - Participates in scenario evaluation (Includes one meeting in Washington, DC)
 - Provides input to scenario evaluation report
- **EPRI**
 - Runs DSS for the scenario evaluation and associated sensitivities
 - Provides input to scenario evaluation report
- **Guidance & Evaluation Committee**
 - Participates in scenario evaluation (Includes one meeting in Washington, DC)
 - Provides input to scenario evaluation report

Phase 2, Task 3: Technical Requirements and Procedure for Evaluation of Second and Third Scenario

In Phase 2, the second and third high priority business cases identified in Phase 1, Task 2 will be evaluated. All activities stated above for Phase 1, Task 3 will be repeated for Scenarios #2 and #3.

Phase 2, Task 3 Deliverable: Four months after Phase 2 subcontract award, a report on the recommended evaluation procedure for Scenarios #2 and #3 will be submitted that includes the following:

- Specification and business case description of potential PHEV-grid support functions
- Requirements for facility monitoring and control to incorporate PHEV support
- Procedure for determining the value proposition of PHEV utility or facility support functions and incremental changes in emissions

Milestone: Go/no-go decision – Models are adequate to perform the business case scenario evaluation.

Team Member Roles: Continue as defined in Phase 1, Task 3.

Phase 2, Task 4: Scenario Evaluation

Scenarios #2 and #3 will be analyzed and the conditions will be identified under which the value to the owner will justify the cost or investment. All activities stated above for Phase 1, Task 4 will be repeated for Scenario #2 and #3.

Phase 2, Task 4 Deliverable: Eight months after the Phase 2 subcontract award, an interim report on the evaluation of Scenario #2 and #3 will be submitted that includes the following:

- Revised (as necessary) specification and business case description of potential PHEV-grid support functions and conditions for a positive value proposition
- Functional specification of PHEV charging infrastructure
- Revised (as necessary) requirements for facility monitoring and control to incorporate PHEV support
- Revised (as necessary) procedure for determining the value proposition of PHEV utility or facility support functions and incremental changes in emissions
- List of potential changes to PHEV requirements or battery charging strategies necessary to support interactive grid-PHEV interface

Team Member Roles: Continue as defined in Phase 1, Task 4.

Phase 2, Task 5: Barrier Identification

For the business cases that have a positive value added, the team will identify any technical and market barriers that must be overcome to achieve market success. A qualitative risk/benefit assessment of the technical barriers and research required to achieve the conditions required for the positive value added will provide guidance to DOE on the best strategies to overcome such barriers, the likelihood of success, and stakeholder-specific risks and benefits of such barrier-mitigation activities. The probability that market barriers will be overcome will also be discussed in terms of the potential (positive and negative) impacts of regulatory changes and the likelihood that the “desired” regulatory changes will in fact be implemented.

Phase 2, Task 5 Deliverable: Ten months after the Phase 2 subcontract is awarded, a risk/benefit report will be submitted that includes a list of technical and market barriers that must be overcome to realize a commercially viable PHEV.

Team Member Roles:

- **SENTECH, INC.**
 - Develops technical and market barriers for each scenario evaluated
 - Performs risk/benefit analysis
 - Prepares and edits report

- GE
 - Assists with interviews of some stakeholders (existing GE business contacts)
 - Provides input on barriers and risk/benefit analysis
- EPRI
 - Provides input on barriers and risk/benefit analysis
- Guidance & Evaluation Committee
 - Provides input on barriers and risk/benefit analysis

Phase 2, Task 6: Application to National and Regional Assessments

Analysis of the case studies, load profile changes, and utilization of generating capacity will provide key indicators of what local/regional characteristics or parameters determine the viability of specific value-added functions or business cases for PHEVs. To the extent possible, the company and EPRI will parameterize these results to provide input to on-going DOE national and regional assessments of PHEVs.

Phase 2, Task 6 Deliverable: Final Report for Phase 1 and 2 will incorporate all the above memoranda and will provide guidance for the application of study results to DOE national or regional PHEV assessments or roadmaps. In addition, the final report on this project will describe the opportunities and barriers for PHEV/grid integration. Opportunities will include the potential value proposition for the consumer and the utility and, in particular, the value of PHEVs as energy storage for the utility. The barriers identified will focus on issues directly related to integrating the vehicle and the grid and what must be developed to make this a viable proposition. The final report will be due fourteen months after the Phase 2 subcontract award.

Team Member Roles:

- **SENTECH, INC.**
 - Assists in the development of methodology to perform regional and national assessments
 - Provides input to regional and national assessments
 - Prepares and edits final report
 - Attends meeting in Washington, DC for presentation of report to DOE
- **GE**
 - Assists in the development of methodology to perform regional and national assessments (Helps assemble data as needed)
 - Provides input for final report and review draft before submission to DOE
 - Attends meeting in Washington, DC for presentation of report to DOE
- **EPRI**
 - Assists in the development of methodology to perform regional and national assessments (Helps assemble data as needed)
 - Provides input for final report and review draft before submission to DOE
 - Attends meeting in Washington, DC for presentation of report to DOE



- Guidance & Evaluation Committee
 - Provides input for final report and review draft before submission to DOE
 - Attends meeting in Washington, DC for presentation of report to DOE

Phase 3

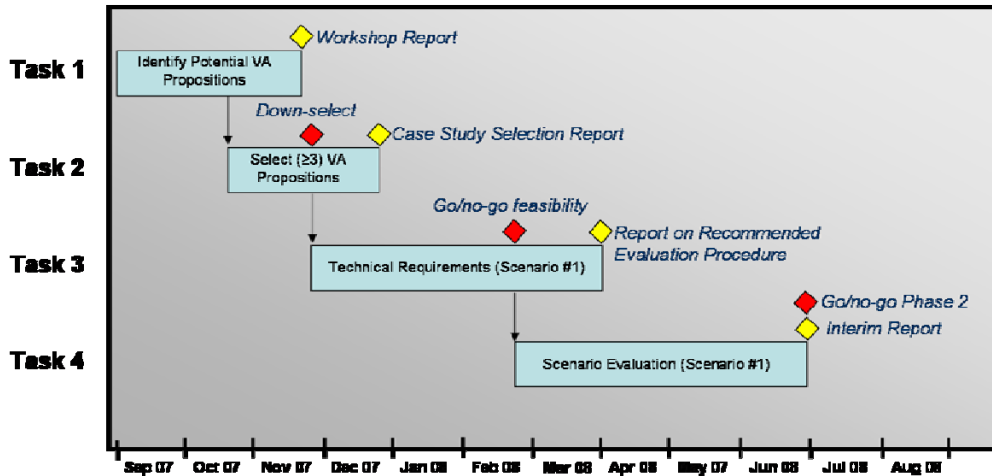
Tasks 3 through 6 may be repeated for additional value added scenarios and/or variants of the first three selected scenarios.

DELIVERABLES

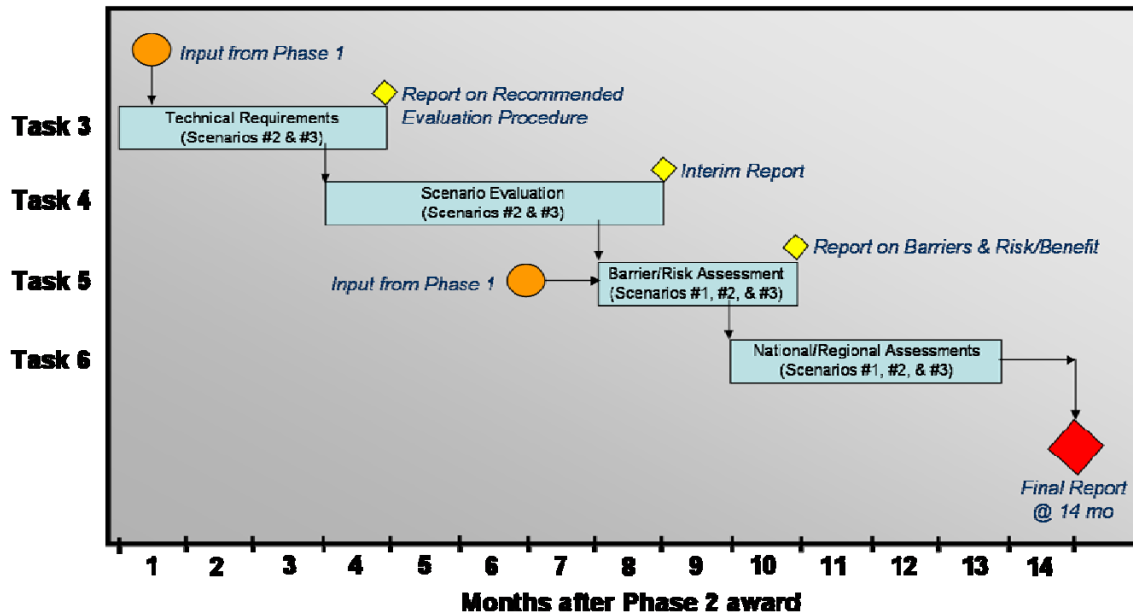
- Specification and business case description of potential PHEV-grid support functions and conditions for a positive value proposition
- Functional specification of PHEV charging infrastructure
- Requirements for facility monitoring and control to incorporate PHEV support
- Procedure for determining the value proposition of PHEV utility or facility support functions and incremental changes in emissions (Three sample case studies applying the methodology will be provided. Depending on the business cases analyzed, this will likely expand to the development of the procedure for determining the value proposition for the vehicle owner or a third party.)
- List of potential changes to PHEV requirements or battery charging strategies necessary to support interactive grid-PHEV interface
- List of technical and market barriers that must be overcome to realize a commercially viable PHEV
- Guidance for applying study results to DOE national or regional PHEV assessments or roadmaps
- Final report (The final report on this project will incorporate all the above memoranda and will describe the opportunities and barriers for PHEV/grid integration. Opportunities will include the potential value proposition for the consumer and the utility and, in particular, the value of PHEVs as energy storage for the utility. The barriers identified will focus on issues directly related to integrating the vehicle and the grid and what must be developed to make this a viable proposition.)

SCHEDULE

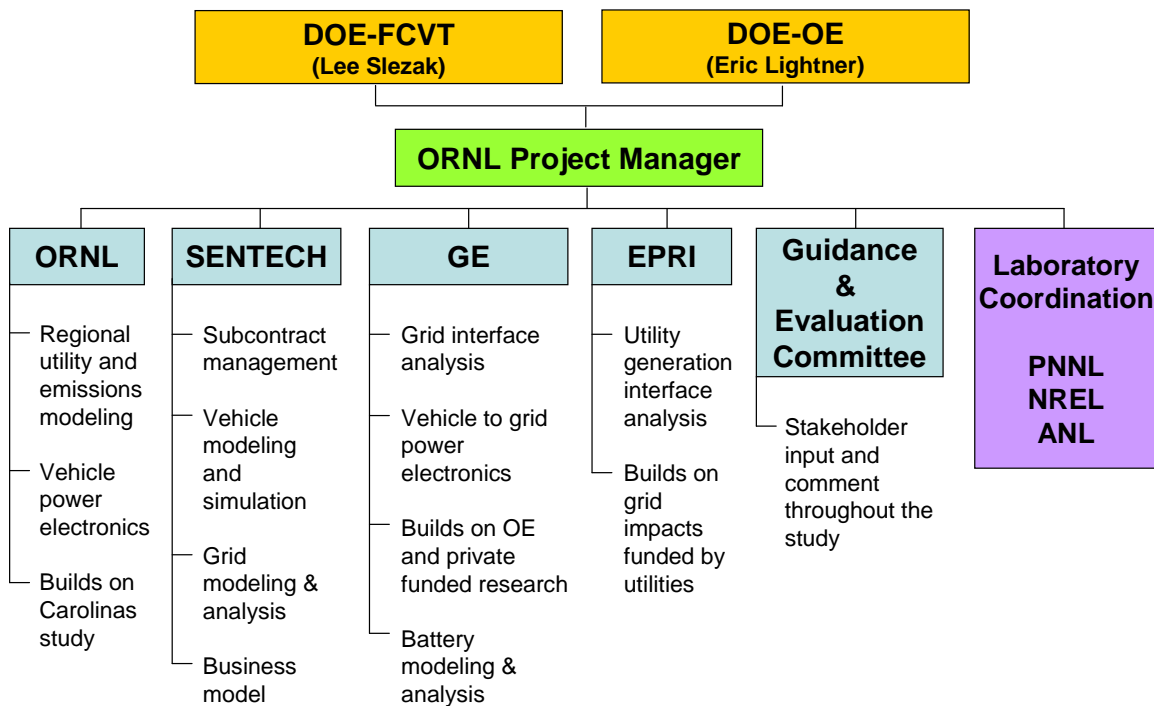
Phase 1



Phase 2



PROJECT TEAM AND ORGANIZATION



TEAM QUALIFICATIONS

SENTECH INC., ORNL, GE, and EPRI have worked together, in various combinations, on many projects. All of the teaming companies have expertise in various aspects of power grid planning and modeling, vehicle modeling, and facility (building) energy analysis. Examples of past related activities by team members are listed below:

- Hawaii microgrid and energy storage assessment
- Integrated distributed generation, renewable energy, demand response and distribution automation on a feeder in New Mexico
- Numerous distributed generation studies and energy storage studies for utilities and regions of the country
- Production cost assessments, including utility, California (power pooling), MAIN (SO₂ reduction strategies), wind integration, and demand-side programs
- Development of a distribution reliability toolkit and integrated (generation, transmission, distribution, customer) reliability assessments

The team will utilize validated, industry-recognized models for vehicles and for all levels of power system dynamics. (In many cases, team members have developed and own these models.) The following models will be applied during the study:

- PSAT – vehicle energy management
- MOVES – vehicle emissions (also GREET, PERE and MOBILE6)
- DSS – distribution, DG, sub-transmission (developed by EPRI)
- MAPS – utility generation & transmission, system loads (developed by GE)
- ORCED – state or regional dispatch (developed by ORNL)

In addition, the project team has familiarity with many models and assessment tools covering the other aspects of vehicle and power system operations. As necessary, depending on the value propositions to be evaluated and the case studies chosen, models will be selected for following as well:

- Generation expansion – utility planning
- Battery charging and performance

The diagram on page 17 portrays the relationships of the proposed models and their scope.

A range of models is necessary because “back of the envelope” estimates of grid behavior are usually inaccurate. The operation of parts of the grid for short time intervals (seconds, minutes, hours) result in constraints on operations of the grid as a whole for longer periods (days, months, years). The interfaces among the different grid subsystems and time intervals are quite complex. To obtain an accurate evaluation of a PHEV value proposition, the value proposition must be portrayed using specific sub-system models, with a hierarchy of models (load node to feeder to substation to transmission to generation to power pool) to obtain a complete understanding of the effects on the power system.

Furthermore, a detailed and case-study-specific modeling approach is necessary because power system behavior is very non-linear and asymmetric. One cannot simply define an “average” or “typical” utility or feeder in order to adequately evaluate a technology. The impact of the average does not equal the average of the impacts. For example, the total effects on a power system, based on the performance of many feeders of varying characteristics, will not be the “scaled up” result of the performance of an average or “typical” feeder.

The project team’s broad expertise and strong industry ties will ensure a comprehensive assessment of candidate value propositions with substantiated conclusions using tools widely accepted by the utility, vehicle, and battery industries. The results should provide directional guidance to the industry, researchers, and policy makers on the ownership and operating modes, vehicle capabilities, charging infrastructure, and market niches needed to promote rapid and viable introduction of PHEVs in the United States.

Application and Interaction of Models

