FreedomCAR and Fuel Partnership

Vehicle Systems Analysis Technical Team

September 2006

Table of Contents

Vehicle Systems Analysis Technical Team (VSATT) Roadmap
September 12, 2006

1. MISSION

The mission of the Vehicle Systems Analysis Technical Team is to evaluate the performance and interactions of proposed advanced automotive powertrain components and subsystems, in a vehicle systems context, in order to provide direction for the various FreedomCAR and Fuel technical teams and Department of Energy (DOE) Energy Efficiency and Renewable Energy (EERE) staff to focus research on areas that maximize the potential for fuel efficiency improvements and emission reduction.

2. OBJECTIVES

Unlike the other FreedomCAR and Fuel Technical Teams' objectives, the Vehicle Systems Analysis Technical Team's objectives or metrics are not tied to specific FreedomCAR goals. The primary VSATT objective is a programmatic support effort that is open-ended to support the aforementioned teams. In addition, the remaining VSATT objectives are largely dependent on having component and systems technologies developed by the Technical Teams or state-of-the-art vehicles provided to the VSATT for validation of in-vehicle performance. That being understood, the objectives of the VSATT are as follows:

- Develop and utilize advanced computer modeling tools to conduct simulation studies of advanced vehicle technologies in support of FreedomCAR and Fuel Technical Teams.
- Interact with FreedomCAR and Fuel Technical Teams to identify and conduct needed component sizing and interface studies to enable focusing of research activities.
- Coordinate with the Fuel Pathways Integration Technical Team that conducts modeling and analysis on hydrogen production, distribution, and dispensing.
- Conduct analyses and simulations to assess and identify vehicle technology pathways that achieve or best approach FreedomCAR and Fuel Research Goals while minimizing cost.
- Conduct simulations and validation testing to obtain data necessary to ensure congruency of FreedomCAR and Fuel Research Goals and provide this information to the FreedomCAR Operations Group.
- Establish and utilize testing facilities, university resources, technologies, and procedures to allow unbiased benchmarking and performance validation of advanced vehicle technologies in support of FreedomCAR and Fuel Technical Teams.

3. TECHNICAL TARGETS

A. Targets

The FreedomCAR and Fuel Partnership Research Goals and Technical Targets for 2010 do not establish technical targets for the vehicle systems analysis activities of the Partnership. However, in order to meet the objectives of the VSATT identified in Section 2, the following targets have been established by the team.

1. Develop and implement vehicle systems simulation software.
2. Conduct component sizing and requirement simulations.
3. Conduct component and systems optimization simulations.
4. Conduct benchmark testing of vehicles that utilize advanced technology systems such as advanced batteries, plug-in hybrid electric vehicle powertrain components, and advanced fuels such as hydrogen.
5. Establish a Hardware-in-the-Loop (HIL) component testing facility.
6. Perform HIL component testing and evaluations.
7. Participate in the development of vehicle test procedures for advanced powertrain systems.
8. Integrate modeling and testing activities related to advanced vehicle technologies.

B. Status

The following chart shows the progress towards completion of each of the eight (8) targets identified above. Note that the analytical and cooperative activities (related to objectives 1, 2, 3, 4, 6 and 8) continue throughout the life of the Partnership due to changing technology and may not reach 100% completion. These are denoted as "on-going" in Figure 1.

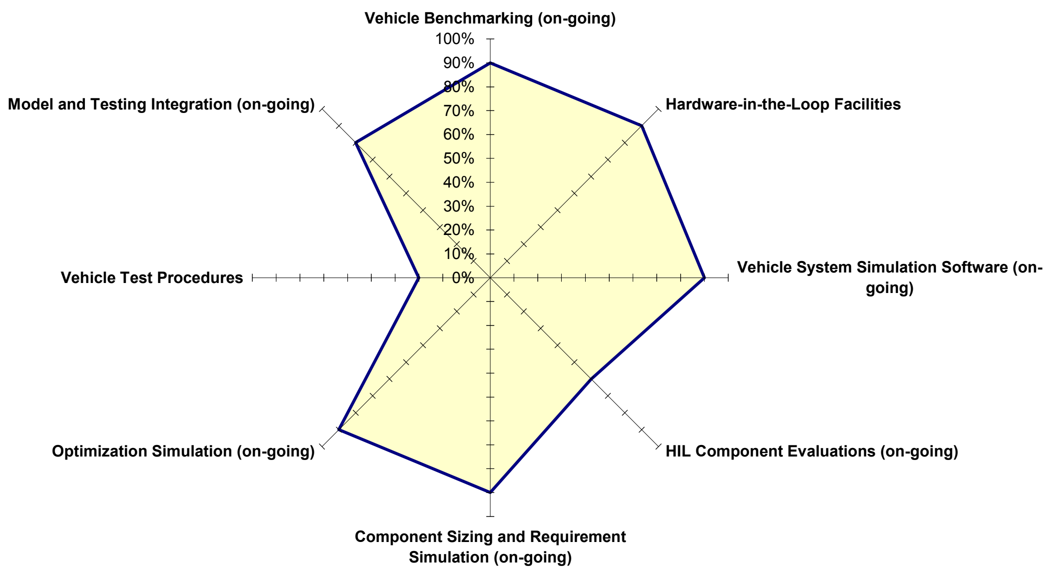

Figure 1. Spider Chart Showing Status & Gaps Related to VSATT Targets

4. GAP ANALYSIS

It is apparent from the spider chart of Figure 1 that sizable challenges remain in the areas of research protocols as well as model-to-testing integration. The most significant of these for the VSATT is participating effectively in the development of standard international research protocols and test (validation) procedures. Organizations such as government labs, EPA, CARB, SAE, FISITA and the IEA are already facilitating/ promoting test standards to lead (or influence) regulatory procedures for advanced technologies such as fuel cells. On the other hand, the VSATT is promoting rigorous research procedures and protocols that standardize testing and analysis methodologies and that enable a common scientific understanding of technical accomplishments and to reduce the overhead (cost) of test procedure development at the labs. The Department of Energy (DOE) and the national labs are promoting cooperative activities in analysis, test planning and laboratory/field testing to identify and address the key issues. Numerical values of the gaps are summarized in Table 1, and the relative magnitudes of the technical challenges are indicated qualitatively, where red indicates a severe challenge, yellow indicates an intermediate level of difficulty, and green represents a reasonable level of confidence that the target can be met.

Table 1. Gap Analysis for VSATT Targets

Target	Completion Percentage
Vehicle Benchmarking (on-going)	90
Hardware-in-the-Loop Facilities	90
Vehicle System Simulation Software (on-going)	90
HIL Component Evaluations (on-going)	60
Component Sizing and Requirement Simulation (on-going)	90
Optimization Simulation (on-going)	90
Vehicle Test Procedures	30
Model and Testing Integration (on-going)	80

5. PROGRAMMATIC STRATEGY

A. Overview

As stated previously, the role of the Vehicle Systems Analysis Technical Team is to provide an over-arching vehicle systems perspective to the technology Technical Teams and activities of the FreedomCAR and Fuel Partnership. As depicted in Figure 2, VSATT uses analytical and empirical tools to model and simulate candidate vehicle systems, validate component performance in a systems level context, benchmark emerging technology, and validate computer models. Extensive collaboration with the FreedomCAR and Fuel Technical Teams is required in both analysis and testing for VSATT to meet its objectives.

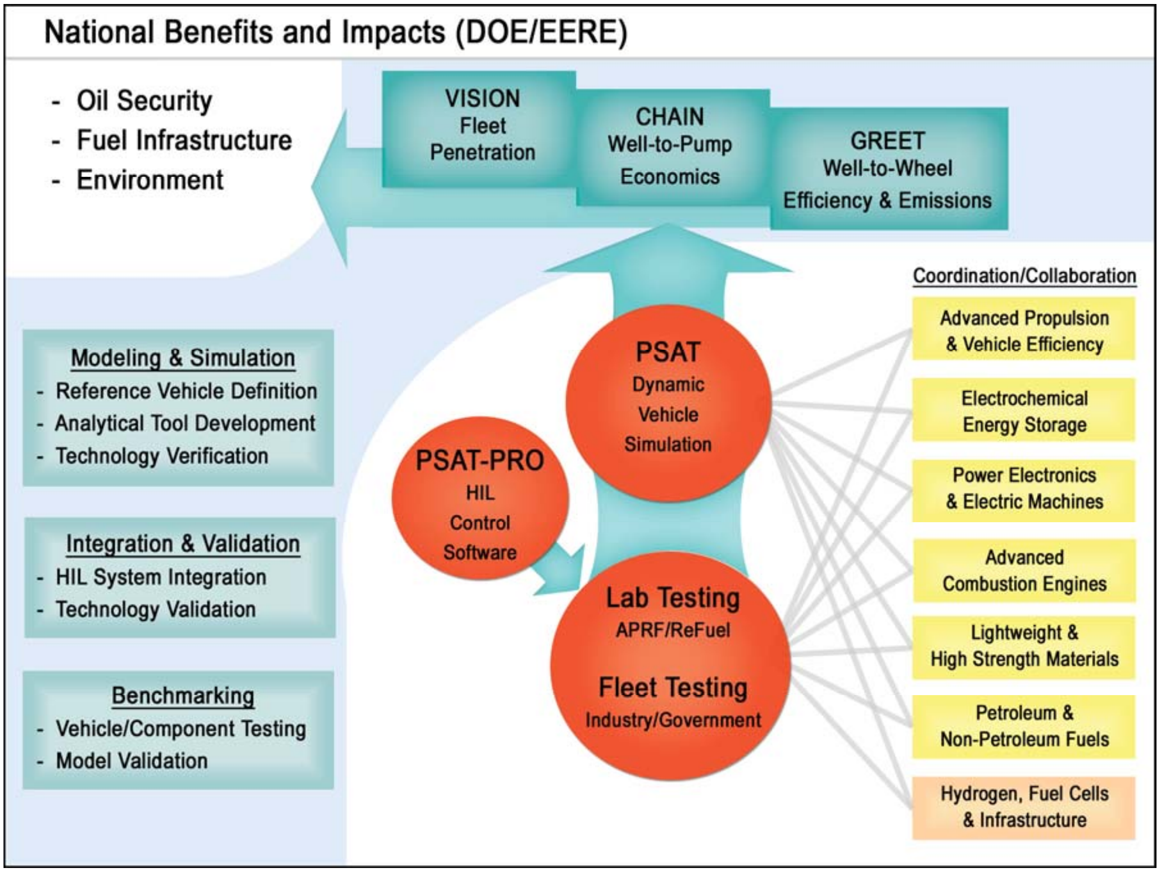

Figure 2. Analytical and empirical tools used to model and validate components and systems and benchmark emerging technologies

B. Programmatic Approach

A unique set of software tools has been developed and is being utilized by the Vehicle Systems Analysis Technical Team to support the FreedomCAR and Fuel Partnership. The tools depicted in Figure 2 are described in the following paragraphs. VISION, CHAIN, and GREET are DOE tools used to forecast national-level energy and environmental parameters including oil use, infrastructure economics, and greenhouse gas contributions of new technologies, based on vehicle-level simulations that predict fuel economy and emissions using PSAT. Dynamic simulation models, such as PSAT, are combined with DOE's specialized equipment and facilities to validate DOE-sponsored technologies in a vehicle context (i.e., PSAT-PRO control code used with actual hardware in a virtual vehicle test environment). The Advanced Powertrain Research Facility (APRF) is used to test light- and medium-duty vehicles (operating on a variety of liquid and gaseous fuels), propulsion systems, and components in controlled environments to acquire fuel economy, efficiency and emissions (scientific) data. Fleet and field tests are used to assess the functionality of technology in the less-predictable real-world environment. Modeling and testing tasks are closely coordinated to enhance and validate models, as well as to ensure that test procedures and protocols comprehend the needs of coming technologies.

PSAT (Powertrain Systems Analysis Toolkit) allows dynamic analysis of vehicle performance and efficiency to support detailed design, hardware development, and validation. A driver model attempts to follow a vehicle driving cycle, sending a power demand to the vehicle controller which, in turn, sends a demand to the propulsion components (commonly referred to as "forward-facing" simulation). Dynamic component models react to the demand (using transient equation-based and physics-based models) and feed back their status to the controller, and the process iterates on a sub-second basis to achieve the desired result (similar to the operation of a real vehicle). The forward architecture is suitable for detailed analysis of vehicles/propulsion systems, and the realistic command-control-feedback capability is directly translatable to PSAT-PRO control software for testing in the laboratory. Capabilities include transient performance, efficiency and emissions (conventional, hybrid, and hybrid fuel cell vehicles), optimization of control strategies, and identification of transient control requirements.

PSAT-PRO (PSAT rapid control PROtotyping software) allows dynamic control of components and subsystems in hardware-in-the-loop (HIL) testing. Component hardware is controlled in an emulated vehicle environment (i.e., a controlled dynamometer and driveline components) according to the control strategy, control signals, and feedback of the components and vehicle as determined using PSAT. The combination of PSAT-PRO and HIL is suitable for propulsion system integration and control system development as well as rigorous validation of control strategies, components, or subsystems in a vehicle context (without building a vehicle). Capabilities include transient component, subsystem, and dynamometer control with hardware operational safeguards compatible with standard control systems.

Laboratory testing applies state-of-the-art facilities to support the development of detailed technology integration requirements; validate advanced technologies; and measure, within a vehicle systems context, progress toward FreedomCAR and Fuel technical targets. In addition, lab tests benchmark components and vehicles to validate models, support technical target setting, and provide data to help guide technology development tasks.

Operational and fleet testing evaluates vehicles in real-world applications to measure progress toward FCVT technical targets and disseminate accurate, unbiased information to potential vehicle users, DOE, industry technology developers, and vehicle modeling tasks. The scope includes vehicles that use DOE-sponsored technology or technologies of particular interest to FreedomCAR and Fuel Partners (i.e., hybrids and internal combustion engine vehicles fueled with hydrogen and other gaseous/ liquid fuels), as well as the related fueling infrastructure. Capabilities include measuring performance, operational costs, fuel consumption, in-use maintenance requirements, and operational characteristics. The execution of these tasks occurs under cost-shared agreements with industrial partners such as electric utilities and automotive companies. Test sites may include utility or government locations where fleet vehicles are used and maintained. National laboratories provide data acquisition, analysis, reporting, and management support.

C. Milestones

Milestones cannot be precisely defined at this time because the VSATT activities are dependent on the availability of data/models and experimental hardware from the other FreedomCAR and Fuel Technical Teams, as well as the availability of technologies from worldwide sources. Once deliverable information is available from the other FreedomCAR and Fuel Technical Teams, appropriate VSATT milestones will be developed.

D. Current Tasks

The VSATT activities and associated tasks are described in the following paragraphs. Most of the activities described will involve extensive coordination and/or collaboration with other FreedomCAR and Fuel Technical Teams, such as the Fuels Pathway Integration Team.

Modeling and Simulation

Analytical tool development—Develop and maintain computer models and analytical tools that will enable simulation of the component technologies and reference vehicles. The tools will comprehend the technology development direction, as well as the needs of the industry partners in the FreedomCAR and Fuel Partnership.

Component Technology Development Support—Provide analytical support to the various FreedomCAR and Fuel Technical Teams to help define component requirements and interface issues from a systems context. This activity will require collaboration with FreedomCAR and Fuel Technical Teams to identify and obtain data on subject component technologies to be modeled and analyzed.

Model to Model Integration—Coordinate modeling activities with various DOE organizations and its subcontractors to improve modeling efficiency and accuracy and better support technology R&D activities. This task will include linking the Automotive Systems Cost Model (ASCM) and GREET modeling tools with PSAT to perform trade-off studies between fuel economy and cost on a total life-cycle basis.

Vehicle Systems Analysis and Simulations—Conduct general vehicle systems modeling studies of various configurations and sizes of hybrid electric, plug-in and fuel-cell hybrid powertrains and identify the resulting potential impacts on the overall vehicle, as well as individual component technologies.

Reference vehicle definition—Develop attributes and specifications for a portfolio of hypothetical "reference vehicles" that represent the spectrum of the vehicle(s) population addressed by the FreedomCAR and Fuel Partnership.
Technology Verification—Incorporate component and subsystem models in the reference vehicles and conduct vehicle simulations to verify performance and ensure compatibility with potential propulsion/vehicle configurations.

Integration and Validation

HIL system integration—Integrate and test experimental component/subsystem hardware in an emulated vehicle environment with realistic control system interfaces and interactions. PSAT-PRO will be used to optimize propulsion system control, leading to refined performance and control requirements to feed back to DOE technology developers and industry partners. This activity will include the completion of an investigation into the suitability of a hydrogen-fueled internal combustion engine advanced HEV.

Technology validation—Validate, within a vehicle systems context, that the technologies developed by the FreedomCAR and Fuel Technical Teams meet their technical targets and are suitable for vehicle applications.

Fuel Economy Studies—Conduct detailed studies of the fuel economy potential of various advanced technologies, including mild, full, and plug-in hybrids, hydrogen internal combustion engine, advanced diesel, and fuel cell vehicles using various fuel types.

Development of testing protocols and standardized validation procedures—Expand collaboration with international automotive community to complete development of standardized vehicle testing protocols and validation procedures.

Benchmarking

Vehicle/component testing—Test and analyze emerging technologies obtained from FreedomCAR and Fuel Technical Teams, as well as worldwide sources, using laboratory facilities and field testing. The results will be distributed to DOE and industry partners, and published to support (re)assessment of the content and targets of R&D activities. This activity will include the following specific tasks, which will be periodically updated as new vehicles of interest are identified and become available:

- Benchmarking of the Gen II Civic HEV, Camry HEV, EnergyCS converted Prius PHEV, Hymotion converted Prius PHEV, Renault Kangoo PHEV, and Renault Clenova PHEV.
- Conduct 160k mile Accelerated Fleet Testing of the Gen II Prius, RX400H, Accord, Gen II Civic, Camry, 2wd and 4wd Escape, and 2wd and 4wd Silverado HEVs. Conduct End of Life Performance Testing when each vehicle reaches 160,000 miles (accumulated with 36 months of testing for each HEV).
- Conduct fleet testing of 10 EnergyCS converted Prius PHEVs, one Hymotion converted Prius PHEV, and Kangoo and Clenova PHEVs from Renault.
- Conduct fleet testing of eight hydrogen ICE vehicles from ETEC/Roush.

Model and Testing Integration—Integrate the modeling, laboratory, and field testing activities to allow for the use of test data to validate the accuracy of the vehicle and component computer models, including overall measures (e.g., fuel economy and state-of-charge of energy storage devices over a driving cycle), as well as transient component behavior (e.g., fuel rate and torque).

E. CURRENT DEMONSTRATIONS

Several indicators as to the success of the VSATT activities exist. The first of which is the successful commercialization of the ADVISOR model developed by DOE’s National Renewable Energy Laboratory to AVL. AVL is now responsible for licensing and model updates and revisions. Another key indicator is that the latest version of PSAT developed by DOE’s Argonne National Laboratory was awarded a 2004 R&D 100 Award and has been licensed by not only the FreedomCAR and Fuel Industry Partners, but also by more than 45 companies and universities including Hyundai Motor Corporation, Delphi, Eaton, Dana, Cummins, and Exxon-Mobil. PSAT is also now being used as the primary modeling tool by universities participating in the DOE’s Challenge X Advanced Powertrain Technology Student Competition.