3.0 Technology Research and Development Plan

3.1 Vehicle Systems

In order to assess the validity of performance targets for each technology subprogram with respect to the overall FCVT Program goals, an integrated systems level approach must be taken. The Vehicle Systems subprogram integrates all other subprogram performance targets to confirm the R&D direction of the FCVT Program. The Vehicle Systems subprogram is comprised of three key activities: Simulation and Technology Validation, Heavy Vehicle Systems R&D, and Light Vehicle Ancillary Systems R&D.

The objectives of the Simulation and Technology Validation element are to benchmark emerging advanced technologies and to evaluate performance targets and data that will enable the FCVT technology R&D teams to focus research on areas that will maximize the potential for fuel efficiency improvements and emissions reduction. In addition, this element also reviews and evaluates the integration of components developed by the FCVT technology R&D teams. The main challenge is to predict how individual technology components will perform in a vehicle environment through computer simulation models, laboratory testing and fleet testing.

Heavy Vehicle Systems R&D encompasses two primary sub-key activities–Heavy Vehicle Systems Optimization (parasitic energy loss minimization, thermal control optimization) and Heavy Hybrid Propulsion Systems R&D. The Heavy Hybrid Propulsion Systems R&D activity will be terminated and an orderly phase-out will be completed by the end of FY 2007 to permit resources to be focused on activities that will have a greater impact on reduction of petroleum use.

Light Vehicle Ancillary Systems R&D focuses on developing more efficient ancillary systems, such as advanced climate control. Inputs to the Vehicle Systems subprogram draw upon the outputs of Advanced Heavy Engine R&D, Advanced Lightweighting Materials R&D, and Hybrid and Electric Propulsion R&D. Data generated as a result of these efforts feeds into enhancing the modeling and predictive capabilities of the Program.

3.1.1 Simulation & Technology Validation

3.1.1.1 External Assessment and Overview

The role of the Simulation and Technology Validation element is to provide an integrated vehicle systems perspective to the technology R&D subprograms and activities of DOE's FCVT and HFCIT Programs. This element uses analytical and empirical tools to model and simulate potential light-duty passenger and heavy-duty commercial vehicle systems, validate component performance within an overall systems level environment, benchmark emerging vehicle level and component technologies, and validate computer modeling and simulation tools. The vehicles using these technologies should be more efficient and must meet current and future emission standards, while remaining competitive with conventional vehicles in terms of cost and reliability. This element also conducts dynamometer and real world, on-road vehicle testing to develop independent, unbiased information on the performance of advanced transportation technologies and to validate modeling results. The combination of modeling, simulation and testing facilitates quicker, less expensive assessment of advanced vehicle technologies within a systems context which subsequently shapes future technology direction, research, and development. Extensive collaboration with the technology development subprograms in FCVT, as well as HFCIT, is required in both analysis and testing for this element to be successful. The analytical results of this element are used to continually update component performance targets and to support the Business Administration's Analytical Team in estimating the national benefits and/or impacts of DOE-sponsored technology development. This key activity also incorporates real world demonstration and evaluation of idle reduction technologies for heavy-duty commercial vehicles.

3.1.1.2 Internal Assessment and Activity History

A forerunner to this key activity was the testing and evaluation of alternative fuel vehicles (AFVs) as a result of the Alternative Motors Fuels Act of 1988. These activities focused on evaluating the performance of AFVs powered by electricity and liquid (i.e. ethanol and methanol) and gaseous (i.e. natural gas and propane) fuels. As technical challenges were overcome and AFVs subsequently matured, the need to evaluate AFVs subsequently waned. In the late 1990s, hybrid vehicles became a major interest due to their potential to significantly improve fuel economy, while utilizing the existing conventional refueling infrastructure. It became important to the Department and its industry partners to develop the ability to simulate, evaluate, and test (under controlled and real world conditions) various hybrid propulsion strategies and hardware components which impact vehicular performance and fuel economy. This need applies not only to light-duty passenger hybrids, but also to heavy-duty commercial hybrids as well as new technology components that are developed and considered for the marketplace. Under these activities, scores of AFVs and hybrid vehicles have been extensively benchmarked and tested under baseline and accelerated use conditions to determine performance, identify needed improvements, and to help focus further research efforts to refine components and systems. Increasingly, the advent of hydrogen as a major fuel of interest has driven the need to evaluate the use of hydrogen in both internal combustion engines and fuel cells in the context of the vehicle and refueling infrastructure. Reducing idling in heavy-duty trucks was identified by DOE in the late 1990s as an ideal way to reduce petroleum consumption. It was soon recognized that many idle reduction technologies are relatively mature and generally do not suffer from significant technical limitations, but do face significant consumer barriers such as high initial cost and limited acceptance resulting from a lack of reliable unbiased performance data. In response, DOE is implementing testing, evaluation, and cost reduction strategies to overcome these barriers.

3.1.1.3 Federal Role

The primary role of this element is to evaluate advanced vehicular technologies, fuels, and control strategies within a systems context and validate through laboratory and field testing to develop an unbiased technology assessment and to provide subsequent feedback and direction to the R&D activities of FCVT and HFCIT. The scope of technologies and systems being examined from Government laboratories and the private sector, the need for highly sophisticated equipment, and the requirement for complete objectivity mandate an inherently Federal role. Additionally, some models developed through this element are used to forecast strictly national-level energy and environmental parameters and benefits. This element plays a major role in ensuring that the President's and the Secretary of Energy's energy and environmental goals for transportation are met by the FCVT Program.

3.1.1.4 Approach

Simulation and Technology Validation will develop, maintain, and use advanced analytical tools, techniques, and test facilities to (1) provide guidance to the technology development subprograms, (2) validate the performance of DOE-sponsored technologies in the context of complete vehicle systems, and (3) benchmark non-DOE programs and technologies at both a component and full vehicle system level. Advanced light-duty passenger and heavy-duty commercial vehicular components, fuels, and control strategies will be assessed both in simulated and real world environments to provide accurate, unbiased information and feedback to both FCVT and HFCIT (as depicted in Figure 1). This element will integrate and test DOE–sponsored experimental component/subsystem hardware in simulated vehicle environments with realistic control system interfaces to quickly and cost-effectively assess component technologies and control strategies. Dynamometer and fleet testing of actual vehicles will benchmark technologies and validate simulation strategies and tools.

A unique set of tools has been developed and maintained to support FCVT research. The tools depicted in Figure 1 are described in the following paragraphs. VISION, CHAIN, and GREET are used to forecast national-level energy and environmental parameters including oil use, infrastructure economics, and greenhouse gas contributions of new technologies, based on FCVT vehicle-level simulations that predict fuel economy and emissions using the ADVISOR and PSAT modeling tools.

Dynamic simulation models (i.e., 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 and actual hardware components in a virtual vehicle test environment). Laboratory testing is conducted at the Advanced Powertrain Research Facility and the Renewable Fuels and Lubricants Facility. Fleet 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 ensure laboratory and field test procedures and protocols comprehend the needs of coming technologies.

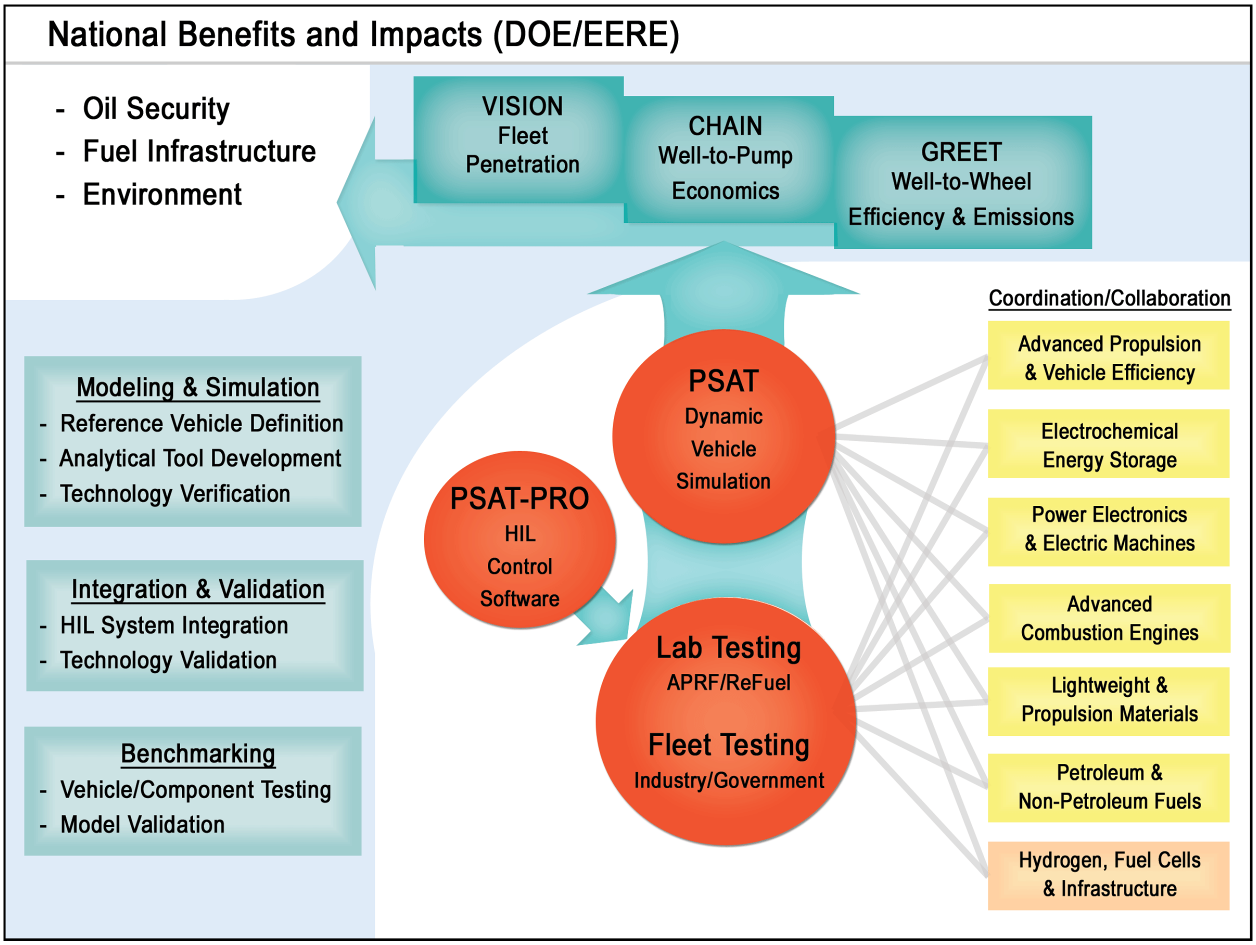


Figure 3.1-1. Analytical and Empirical Tools to Model and Validate Components and Systems Benchmark Emerging Technologies

ADVISOR (ADvanced VehIcle SimulatOR) is used to understand trends and preliminary vehicle design through quasi-static analysis of component performance and efficiency characteristics to estimate fuel economy. Vehicle power demand on the road is used to calculate the demand on propulsion system components and their resulting characteristics each second (using static component map data). These values are summed to produce overall results for a driving cycle (commonly referred to as "backward-facing" simulation). This approach to simulation is suitable for quick evaluation of multiple scenarios due to low execution times and reduced numerical processing. Capabilities include component selection and sizing (conventional, hybrid, and fuel cell vehicles), energy management strategies, optimization, and target development.

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 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 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 fuel cell vehicles), development and optimization of energy management 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 testing. Real hardware components are 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 DOE-sponsored technologies, and measure, within a vehicle systems context, progress toward FCVT technical targets. In addition, lab testing benchmarks vehicles and components to validate models, supports technical target setting, and provides data to help guide technology development tasks. The Advanced Powertrain Research Facility and the Renewable Fuels and Lubricants Facility are used to test light-duty passenger, medium-duty commercial and heavy-duty commercial vehicles, and components operating on a variety of liquid and gaseous fuels and propulsion systems in a controlled environment to acquire scientific data.

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, and industry technology developers and vehicle modeling tasks. The scope includes vehicles that use DOE-sponsored technology or technologies of particular interest to FCVT (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, costs, fuel consumption, in-use maintenance requirements, and operational characteristics including braking and handling. Operational and fleet testing develops test protocols and performance goals and collaborates with public and private entities to collect performance data and other relevant information. 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, government, or commercial locations where fleet vehicles are used and maintained. National laboratories provide data acquisition, analysis, reporting, and management support.

Under fleet testing, idle reduction demonstration and evaluation focuses on data collection, cost reduction, and education and outreach activities to overcome barriers to the implementation of idle reduction technologies in heavy-duty trucks. Data collection and demonstration activities include evaluation of fuel consumption, cost, reliability and durability, engine and accessory wear, and driver impressions. Cost reduction activities are focusing on development and evaluation of advanced idle reduction technologies for on-line, factory installation.

3.1.1.5 Performance Goals

The goal of the Simulation and Technology Validation key activity is to use an integrated systems approach to develop, maintain, and employ analytical tools, techniques, and test facilities to:

- benchmark emerging advanced vehicle and component technologies,
- refine and focus technology R&D performance targets,
- support the development and validation of DOE-sponsored technologies in an integrated vehicle systems context, and
- project fuel savings and environmental benefits of vehicular technology combinations.

These efforts will be conducted annually at a minimum and more frequently as needed for new initiatives or technology introductions.

For idle reduction technologies, the goal is to conduct technology evaluations and collect data required to overcome remaining market barriers, thus maximizing the introduction and use of idle reduction technologies in heavy-duty commercial vehicles.

3.1.1.6 Strategic Goals

Key strategic goals are to:

(1) Facilitate the integration, adoption, and subsequent commercialization by OEMs of high efficiency and alternative fuel vehicular technologies developed through FCVT and HFCIT-supported R&D programs.

(2) Help hybrid electric vehicles account for a significant portion of new vehicle sales in the future to promote energy security and improve air quality.

3.1.1.7 Market Challenges and Barriers

Major market barriers facing this element are:

A. ***Risk Aversion.*** Manufacturers are reluctant to introduce new technologies that may in the future become warranty or liability issues; this aversion is especially acute without a strong demand for the technologies from the marketplace. Unfortunately, high fuel economy in light-duty passenger vehicles has historically been low on the priority list of consumers.

B. ***Cost.*** Effective, timely evaluation of advanced vehicular components and configurations: Historically, integration and evaluation of advanced technologies has required multiple vehicle builds and long term testing which is expensive and time consuming.

3.1.1.8 Technical (Non-Market) Challenges/Barriers

Major technical challenges facing this element include:

C. ***Lack of standardized test protocols.*** Currently, there are no universally standardized test protocols for measuring performance, fuel economy, environmental benefits, reliability/durability, or validating system level improvements in advanced vehicles. Furthermore, current heavy-duty protocols and certification procedures rely on engine testing alone and do not adequately address heavy hybrid vehicle propulsion system operation. New heavy hybrid test protocols and procedures are required to validate heavy vehicle hybridization technology

D. ***Computation models, design and simulation methodologies.*** Codes for optimizing future designs, and for accurately predicting the fuel economies of advanced heavy-duty commercial vehicles on which the technologies are to be applied, are either not fully developed or not currently available.

E. ***Constant advances in technology.*** Current and future advances in respective technologies require modeling and simulation tools to be continually updated and/or enhanced in order to ensure the accuracy of simulation results.

F. ***The dearth of hydrogen fuel cell components and vehicles and hydrogen refueling infrastructure hardware.*** The limited availability of fuel cell components and hydrogen refueling infrastructure hardware hinders the enhancement and validation of simulation codes and tools.

3.1.1.9 Strategies for Overcoming Barriers/Challenges

The Simulation and Technology Validation element will continue to develop, maintain, and exercise advanced analytical tools, techniques, and laboratory and field testing to (1) provide guidance to the technology development elements and (2) validate the performance of DOE-sponsored technologies in the context of complete vehicle systems.

The approach comprises four concurrent and interrelated activities:

(1) Modeling and Simulation,
(2) Integration and Validation,
(3) Laboratory Testing and Benchmarking, and
(4) Operational and Fleet Testing

This approach is best suited to meet the FCVT goals because it will provide timely, cost-effective simulation and validation of various technologies, system architectures, and control strategies to feedback to FCVT and HFCIT R&D subprograms, as well as provide projections of fleet fuel economy and emissions to assess the effectiveness of the FCVT Program.

3.1.1.10 Tasks

A description of the Simulation and Technology Validation tasks, along with estimated duration and barriers is provided in Table 3.1-1.

Table 3.1-1. *Tasks for Simulation and Technology Validation*

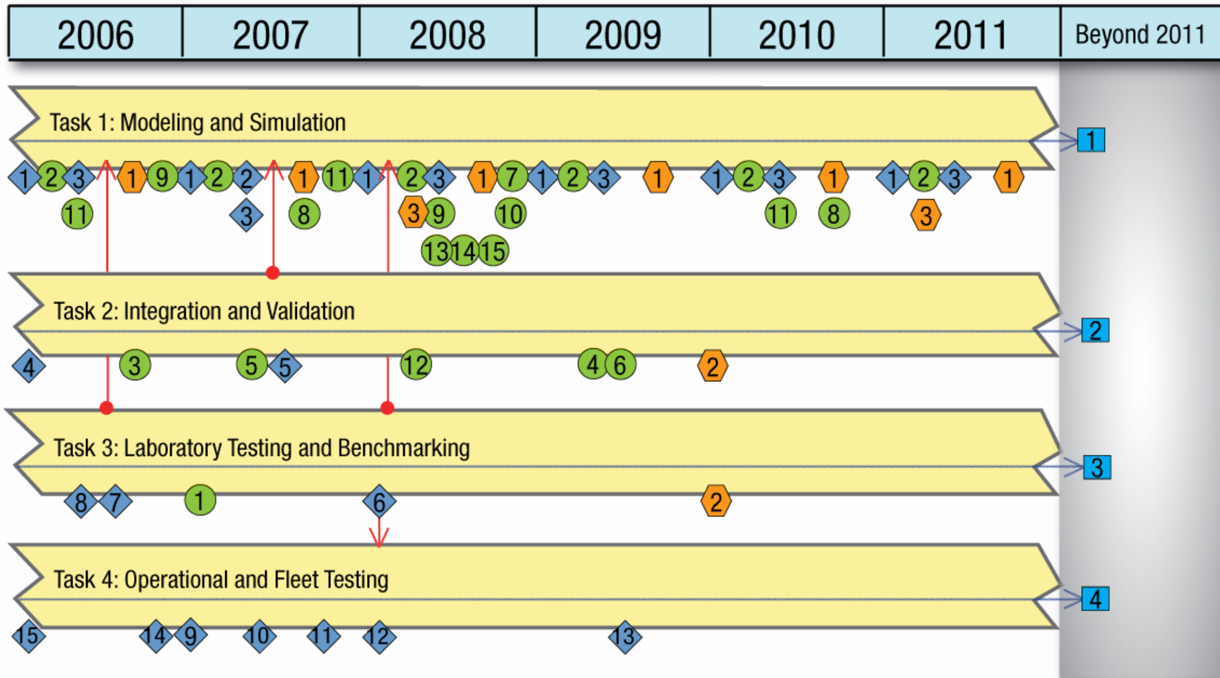
Task	Title	Duration & Barriers
1	***Reference Vehicle Definition and Target Evaluation*** • Annual revision to reference vehicle definitions • Annual evaluation of technical Program targets and overall FCVT goals	84 months (annual updates) Barrier E
	Analytical Tool Development • PSAT updates to reflect technology advances • Addition of Heavy Vehicle component models and powertrain configurations to PSAT	84 months (annual updates) Barriers D, E
	Technology Verification • Characterization of plug-in hybrid vehicles • Challenge X competition PSAT support • Continuous analytical verification of new and emerging advanced technologies	84 months Barriers D, E
	Model Validation • Validation of MY04 Prius and MY05 Accord PSAT models from benchmark data • Continuous validation as data becomes available from benchmarking and fleet testing activities	84 months Barriers A, B, C, D ,E, F

2	***HIL System Integration*** • Design, fabrication, and implementation of Mobile Advanced Technology Testbed (MATT) • Installation, instrumentation, and optimization of the hydrogen-fuelled 2.3L ICE	24 months Barriers B, C, F
	Technology Validation • Fuel cell validation • Continuous validation of emerging advanced technologies as they become available from industry and R&D activities	84 months Barriers A, B, C, E, F
3	***Laboratory Testing and Benchmarking*** • MY05 Honda Accord Hybrid full benchmark • Plug-in hybrid evaluation • Hydrogen fuel cell full benchmark • EOL testing of 1st generation Prius and Insight • Baseline testing of advanced vehicles prior to initiation of accelerated life fleet testing • Benchmarking activities of emerging/new advanced technologies subject to availability	84 months Barriers A, B, C, E, F
4	***Operational and Fleet Testing*** • Annual advanced vehicle technology outlook • Idle reduction technology field evaluations • Advanced hybrid transit bus testing • Hydrogen fuel cell fleet testing • Fleet testing and data collection of hybrid, H2 ICE, fuel cell, and other advanced vehicles	84 months Barriers A, C, F

Section 3.1.1.11 Milestones and Decision Points

Milestones cannot be precisely defined because this element is dependent on the availability of data/models and experimental hardware from other FCVT and HFCIT technology development subprograms, as well as the availability of technologies from worldwide sources. Therefore, the milestone schedule reflects annual updates and is subject to annual revision. (Note: These milestones are tracked on a monthly basis).

Simulation and Technology Validation Network Chart



Legend

Milestone

1. Simulation software revision release
2. Complete assessment of dual energy storage technology
3. Program technical targets evaluation and review
4. Completion of MATT system
5. Fuel cell validation
6. Hydrogen fuel cell benchmarking complete
7. Plug-in hybrid evaluation complete
8. MY05 Accord hybrid benchmarking complete
9. Idle reduction demo #1 final cooler report
10. Idle reduction demo #2 final report on road evaluations
11. Idle reduction demo #3 complete analysis and final report
12. Complete on-line installation of idle reduction technologies
13. Hydrogen fuel cell fleet testing complete
14. 2nd Generation Orion hybrid bus testing completed
15. Technical and economic evaluation of APS Hydrogen Fueling Pilot Plant

Supporting Input

1. Hydrogen fuel cell vehicle for benchmarking and fleet testing activities (from industry)
2. Revised program targets from each technology area
3. Fuel cell sub-system for integration and validation (from industry)
4. Integrated motor/inverter to meet FreedomCAR goals from Advanced Power Electronics and Electric Machines
5. Prototype internal PM motor from Advanced Power Electronics and Electric Machines
6. Thermal control system from Advanced Power Electronics and Electric Machines
7. Hybrid body-in-white weight and performance data from Automotive Lightweighting Materials
8. Advanced Competition performance data available for PSAT enhancement
9. Technical data from Waste Heat Recovery
10. Technical results from Combustion and Emissions R&D
11. Technical data from Heavy Truck Engine R&D
12. Validated power electronics cooling technology available
13. 42V battery/ultracapacitor technical information from Energy Storage R&D
14. Hybrid fuel cell battery prototypes and technical results from Energy Storage R&D
15. New candidate battery technical information from Energy Storage R&D

Technology Program Output

1. Revised targets for advanced technology components and subsystems
2. Validated technologies to industry
3. Simulation support to Advanced Competitions

Recurring/On-going

1. Model validation
2. Component validation, contingent on technology availability
3. Advanced vehicle benchmarking, contingent on technology availability
4. Fleet testing and accelerated life testing, contingent on technology availability

Figure 3.1-2. Network Chart for Simulation and Technology Validation

3.1.2 Heavy Vehicle Systems R&D

3.1.2.1 External Assessment and Market Overview

It is axiomatic in the heavy-duty commercial vehicle industry that only real-world, real-time performance data from actual use in revenue-bearing service are considered sufficiently cogent to deem a technology development mature enough that introduction to the market place can be considered. This situation is compounded by stringent Federally-mandated emissions standards for 2007 and 2010 which are currently the truck and engine manufacturers' primary concern. Manufacturers are focusing on achieving these standards which typically require implementation of more advanced emission control systems that drive up vehicle cost and tend to negatively impact vehicular fuel economy. In addition, presently high fuel costs are cutting into already very tight trucking margins. These factors tend to reduce the trucking industry's inclination to develop and the availability of their resources to implement innovations in energy efficiency.

3.1.2.2 Internal Assessment and Activity History

DOE has been conducting research and development on heavy-duty commercial vehicles since the 1980s to improve efficiency, reduce emissions, and enhance alternative fuel compatibility. Historically, the Department has focused on improving the thermal efficiency of the diesel engine as the primary means of improving fuel economy. Significant gains have been achieved via improved thermal efficiency but have been increasingly compromised as a result of tradeoffs required to achieve ever stricter Federally-mandated emissions standards. Recognition of this fact and extensive modeling studies in the 1990s elucidated the potential fuel economy improvements achievable through heavy-duty commercial vehicle systems. Significant improvements in fuel economy can be achieved through a variety of novel means including reduced aerodynamic drag and engine parasitic losses arising from surface interactions within the engine, improved control and distribution of electrical and thermal systems on board the vehicle, waste heat recovery, reduced ancillary losses, implementation of regenerative shocks and predictive cruise control, reductions in truck idling, and the use of heavy hybrid propulsion systems. This element covers two primary areas–heavy vehicle system optimization and heavy vehicle hybrid propulsion systems.

3.1.2.3 Federal Role

Highway and off-highway heavy-duty commercial vehicles account for upwards of one quarter of all petroleum consumed by the U.S. transportation sector. Presently, the heavy-duty trucking industry is focused on cost-effectively meeting increasingly stringent federally mandated emissions standards for years 2007 and 2010. As a result, improvements in the fuel economy of heavy-duty trucks are largely stagnant and the trucking industry is unable to commit significant resources due to the necessity of meeting emissions standards and very low business margins. Additionally, a strong Federal role in improving the fuel economy of heavy-duty commercial vehicles is necessary due to highly technical R&D requirements and the need for sophisticated tools and modeling capabilities to identify and implement strategies.

3.1.2.4 Approach

To accomplish the goals of this key activity, methodologies identified to reduce energy losses must be developed and tested in the laboratory, and they must then be prototyped and tested on board a heavy-duty commercial vehicle. Subsequent to technology validation, on-road data must be accumulated to determine the durability, reliability, and life-cycle cost of the developmental component and/or design strategy.

A. *Heavy Vehicle Optimization*

Through heavy vehicle optimization, DOE–industry cost-shared R&D tasks develop enabling technologies for reduction of parasitic energy losses, supported by national laboratories and universities, as described in the following paragraphs.

Aerodynamic Drag Reduction. The long-term goal is 25 percent improvement in fuel economy at 65 mph. The relationship between aerodynamic drag and vehicular efficiency is very close to two to one; that is, a 50 percent reduction in drag will result in a 25 percent increase in energy efficiency. Research sponsored by DOE has identified both active and passive methodologies that are capable of producing very large changes in the pertinent parameters and thus achieving significant fuel savings and concomitant emissions reductions cost-effectively. The primary issues that must be addressed are the durability, reliability, life-cycle cost benefits, and actual performance parameters for the various candidate methodologies. An aerodynamic phenomenon known as the Coanda effect has shown some promise in rendering heavy-duty long-haul Class 7 and 8 trucks more energy efficient. However, its viability in this regard is still being investigated. Computational fluid dynamics (CFD) tools and simulation models are being developed and used to assess various drag reduction techniques. The models will be compared with data derived from fractional-scale and full-scale vehicles in wind-tunnel tests simulating on-road wind and air flow conditions at various vehicular speeds, with varying geometries and yaw angles. These results will be used to help efficiently direct truck modification approaches and systems changes that can more rapidly achieve market introduction and acceptance of the technologies. Prototypical aerodynamic drag reduction devices will be validated in fleet demonstrations in actual on-road, revenue-bearing service; and data will be accumulated on efficiency, durability, reliability, maintenance, and service. Development of innovative concepts will continue, including formulation of codes based on vorticity rather than conventional grid elements. A pneumatic drag reduction device, which can also increase tractor-trailer stability and improve braking, will be characterized. Efforts will continue on underhood airflow and thermal management with the goal of reducing aerodynamic drag and achieving more efficient cooling.

Significant reductions in aerodynamic drag lead to new challenges for braking, as heavy-duty commercial vehicles rely heavily upon drag to stop. An air disk brake system is under development to compensate for the expected increase in brake loads that result from reduction in aerodynamic drag. This system will use Si/SiC composite rotors and a composite material for the brake pads and is expected to improve overall braking effectiveness, reduce stopping distances substantially, and reduce brake fade in high-heat conditions. Braking R&D will be conducted in concert with the Department of Transportation's goal of reducing stopping distance by 30 percent by 2010. CFD will be used to modify undercarriage air flow to direct more cooling to the brakes and to reduce drag. Additionally, a joint DOE/DOT program will address tire "splash and spray" that represents a safety hazard.

Friction and Wear Reduction. Modeling codes predict that reductions in the coefficient of friction of key engine components and improved lubricants can lead to 2 and 3 percent improvements, respectively, in heavy-duty truck fuel economy. Significant parasitic energy losses arise from the multiple surface interactions that occur in heavy vehicle systems. Examples of such interactions occur between numerous moving engine components, shafts and impellers in various pumps for fluid circulation, axles, rotors, and the like. A number of promising surface modification technologies have been identified that may be used to significantly alter and control surface interactions and the friction forces and wear that occur at those areas. Moreover, techniques are now available that allow near-atomic-level observation of both the surface-to-surface interaction mechanisms and the lubricant-surface interactions. The latter is expected to lead to methodologies to improve the formulations of both lubricants and their additive packages. This will substantially improve the performance of lubricated surfaces and their special lubricants, contributing to the reduction of the parasitic losses for which they are currently responsible. To systematically characterize such surface and lubricant interactions, experiments have been undertaken to develop a fundamental understanding of the boundary-layer lubrication and surface-failure mechanisms of critical components in engines and vehicle subsystems that are oil-lubricated. Candidate coating and lubrication technologies, in addition to surface modification techniques to reduce friction/wear, will then be evaluated. Subsequently, prototype systems are expected to be constructed and subjected to simulation of operating conditions to provide performance data for further scale-up to on-road utilization and systems characterization prior to commercialization efforts.

Essential Power Systems (EPS). EPS's are a crosscutting technology that addresses the efficient management of electrical and thermal systems and the distribution and control of energy on board the heavy vehicle. EPS's are part of a systems approach to using on-board energy efficiently. Within the EPS approach, concepts to reduce energy losses will include diesel auxiliary power units (APU); lightweight, efficient heating and air-conditioning systems; and electrification of various vehicle components. The latter is promising because significant amounts of energy are consumed by belts and gears in oil, water, and air pumps. Electric motors are substantially more efficient than belt drives and gears. Moreover, the decoupling of the components from the engine drive shaft permits greater opportunities to optimize the locations of accessory components and better usage of available volume. In addition, the ability to operate the electrified components on-demand, instead of the current practice of using them at maximum or near-maximum output, will contribute to attaining 8 percent greater energy efficiency.

Idle reduction. DOE has identified reducing heavy-duty truck engine idling as an effective means of conserving fuel, reducing undesirable emissions, and mitigating high noise levels in stationary idling locations. Products have been available for heating the cab/sleeper, but few have addressed cooling it. These products, along with the EPS and truck electrification technologies that DOE and industry are developing, enable nearly complete idling elimination. Only about 1 percent of U.S. trucks are outfitted with idle reduction devices, while the equipment is carried by 70 percent of trucks in Germany. To combat the inertia in the U.S. trucking industry and better inform truck drivers, individual owner-operators, and fleet operators, DOE has prepared informational brochures and informative sample calculations demonstrating the potential cost savings for fuel based on the actual engine operating conditions used by an individual driver. This industry specific literature is distributed directly to truckers at trade shows and meetings at a DOE/FCVT booth. These activities are being conducted in conjunction with the idle reduction technology evaluations under the Simulation and Technology Validation efforts discussed previously. It is estimated that full penetration of idling-reduction devices in the long-haul truck fleet could save up to 1.5 percent of the total fuel used in the surface transport sector.

Locomotive Systems. The railroads are coming under increasing pressure from the state of California and the EPA to substantially reduce the emissions produced by diesel locomotives. In addition, the rail companies have an increasing need to reduce their operating costs. DOE has entered into two cooperative agreements with locomotive companies to develop strategies, hardware, and operational equipment to reduce emissions and increase fuel efficiency. These will address the recovery of energy dissipated during dynamic braking, the use and development of affordable electrical energy storage devices, and the application of variable-frequency power conversion devices.

Exploratory Research. The Department is continuing to conduct exploratory research in technologies that have the potential to significantly improve heavy-duty commercial vehicle fuel efficiency but are not currently under serious consideration as a near-term technology by industry. Competitive solicitations are being issued to address these novel approaches to improving fuel efficiency, with project cost-sharing based on level of risk. The following projects comprise the Exploratory Research activity.

- *Predictive Cruise Control.* It has been estimated that using modern computer control of the engine to help the driver determine the optimum vehicle speed could improve fuel efficiency in long-haul, heavy vehicles by up to 5 percent. Modeling and simulation of this control scheme confirm these estimates. On-road equipment has been designed and installed in a vehicle that will be tested under experimental conditions to determine the magnitude of the energy savings that are actually achievable.
- *Off-highway Systems.* Off-highway heavy vehicles are faced with energy efficiency and emissions issues similar to those of on-road vehicles. However, they have unique challenges: limited heat rejection capabilities because of the lack of “ram air”; high noise levels that are subject to legislated restrictions (now in Europe, perhaps soon in the United States); and severely restricted under-hood volume for the addition of fuel efficiency, emissions-reduction, or noise-abatement devices. A DOE/industry collaborative task has been initiated to develop a highly efficient radial fan to substantially increase cooling capacity for off-road vehicles; it will enable the use of advanced technologies to reduce emissions and increase the energy efficiency of off-highway vehicles despite increased levels of heat to be rejected.
- *Diesel Reformer Development.* The reformation of diesel fuel could provide a ready supply of carbon monoxide and hydrogen for use directly in the combustion process or in catalyst regeneration. However, because of its higher carbon content, trouble-free reformation of diesel fuel has remained largely elusive and “coking” has been a constant problem with the various technical approaches. An innovative concept will be developed and tested for an auto thermal diesel reformer that has high yield and can potentially avoid the coking phenomenon. The ability of the device to produce desirable hydrogen gas from

conventional diesel fuel will be determined, and preliminary reliability and durability will be assessed. Hydrogen gas production will be compared with the amounts needed for catalyst regeneration, direct injection into the cylinder to facilitate cold starting, and, possibly, use in fuel cell operation. Based on the results of bench tests, a prototype will be constructed and integrated with an engine system.

- *Thermal Control.* The need to use exhaust gas recirculation (EGR) in heavy-duty engines to meet EPA emissions requirements will impose severe operating conditions on conventional cooling systems. It has been estimated that an increase of up to 40 percent in heat load will result from the EGR approach, and the industry consensus is that radically new approaches to heat rejection will be needed to prevent decreased energy efficiencies in the system, higher power requirements that increase parasitic energy losses, and potentially a need to redesign the nose of the tractor, which would lead to less aerodynamic vehicles that increase parasitic energy loss. Basic research on improving the performance of vehicle thermal control systems through the examination of critical heat flux measurements will be conducted to determine if this approach is practical and controllable enough to address the issues. The development of nanofluids for cooling systems will be pursued, based on experimental results that indicate at least a four-fold increase in their thermal capacity over conventional coolants. Phase-change heat transfer through evaporative cooling and the use of high-temperature coolants in advanced engine cooling strategies will also be explored. Experimental data will be provided to a national laboratory for benchmarking the newly developed 3 Dimensional CFD code describing under-hood thermal distributions. It has been estimated that the use of one or more of these technologies could reduce the parasitic energy loss by more than 10 percent, despite the increased heat rejection requirements due to the EGR approach.

B. Heavy Hybrid Propulsion.

The goal of the Advanced Heavy Hybrid Propulsion System (AHHPS) activity, a cooperative government/industry heavy hybrid activity, is to develop advanced, next-generation heavy hybrid components and vehicle systems. An initial technical objective is to develop and demonstrate cost-effective, advanced, next-generation heavy hybrid components and subsystems, which at the vehicle-level could contribute to or enable up to a 100 percent increase in powertrain fuel efficiency relative to today's conventional powertrain technology, while meeting year 2007 Environmental Protection Agency emissions standards. This activity will be terminated and an orderly phase-out will be completed by the end of FY 2007.

One of the issues to be addressed in the commercialization pathway for heavy hybrid propulsion is the extended reliability and durability requirements of heavy-duty commercial vehicles compared to light-duty passenger vehicles. To realize the benefits of heavy hybrid propulsion, the technologies must first be developed to a level suitable in both performance and ruggedness for use in severe operating environments. Much of the development for the automotive market falls well short of being applicable to the world of heavy-duty vehicles. Maintaining or increasing vehicle and component reliability and durability through this technology development effort is a major objective. Heavy vehicles can typically have lifetime requirements up to 10 years of operation and 500,000-1,000,000 miles. The advanced, next-generation technologies sought in the heavy hybrid propulsion R&D effort seek to satisfy these objectives while providing a clear advantage in increasing energy efficiency and reducing fuel consumption.

Program objectives are being addressed through a multi-phase research and development activity. Phase I technology development is designing, developing, characterizing, and showing feasibility of energy and fuel saving in multiple Class 3 to Class 8 heavy hybrid vehicles. Phase I will demonstrate fuel efficiency improvements of 23 to 67 percent in prototype vehicles. Phase II, beginning in 2006, will provide for further advanced technology developments to validate fuel savings up to 100 percent beyond the baseline.

Four industry teams were chosen in Phase I representing a diverse set of vehicle applications and vocations spanning the range of Class 3 to Class 8 heavy duty commercial vehicles. The teams are developing a wide range of technologies including: advanced engine systems, power electronics and electric motor/generator subsystems, energy storage, auxiliary load electrification, and waste heat recovery systems. Vehicle systems modeling, optimization and test validation using heavy hybrid vehicle test procedures and protocols developed by the industry teams and the national laboratories support the research and development activities.

The four industry teams that are developing and validating advanced heavy hybrid technologies for specific architectures in Phase I include:

- General Motors/Allison – advanced parallel hybrid powertrain for transit bus applications
- Eaton/International Truck – advanced parallel hybrid powertrain for Class 4-6 vehicle applications
- Oshkosh/Rockwell/Ohio State University – advanced series hybrid powertrain for Class 7-8 vehicle applications

- Caterpillar – several vehicle applications utilizing waste energy recovery.

Phase II R&D will further the development of advanced, next-generation heavy duty component and vehicular systems and is intended to transfer technologies and know-how into the industry design knowledge base to support wide spread commercialization of these heavy hybrid propulsion systems. Technologies needed to obtain additional fuel economy results for heavy-duty vehicles include:

- Advanced and novel engine prime power concepts
- Low cost, high efficiency, and light weight power electronics
- Advanced energy conversion and energy storage technologies
- Advanced transmission and powertrain components
- Advanced computerized powertrain algorithms
- Advanced thermal and fluid management concepts
- Advanced materials for hybrid powertrains
- Advanced computer modeling for powertrain, component, and vehicle system design optimization and evaluation
- Validated drive cycles for representative Class 3 to Class 8 vehicles.

3.1.2.5 Element Performance Goals

A. *Heavy Vehicle Optimization*

In general, the goal is to reduce parasitic energy losses from non-engine components of heavy vehicles. Specifically, the goal is to:

- Develop technologies that reduce parasitic energy losses, including losses from aerodynamic drag and ancillary systems, from 39 percent of total engine output to 24 percent in 2006.

Specific 2012 technology goals defined by government and industry for the 21st CTP supported by this activity are:

- Develop and demonstrate advanced technology concepts that reduce the aerodynamic drag of a Class 8 highway tractor-trailer combination by 20 percent (from a current average drag coefficient of 0.625 to 0.5).
- Develop and demonstrate technologies that reduce essential auxiliary loads by 50 percent (from the current 20 horsepower to 10 horsepower) for Class 8 tractor-trailers.
- Develop and demonstrate lightweight material and manufacturing processes that lead to a 15 to 20 percent reduction in tare weight (for example, a 5000-lb weight reduction for Class 8 tractor-trailer

combinations), consistent with drivability, safety, stability, and durability.

- Develop and demonstrate a 5-kW, $200/kW diesel-fueled ICE APU by 2007.
- Develop and demonstrate a fuel cell APU system in the 5–30 kW range, capable of operating on diesel fuel, at a delivered cost of $400/kW by 2012.
- Develop consistent electrical codes and standards that apply to both truck (onboard) and truck stop (stationary) electrification technologies to enable the introduction of new idle-reduction technologies.

A series of seven technology-specific DOE-sponsored workshops were held from 1996 to 2002 in which enabling technologies were identified. As a result, technology plans and technology roadmaps were developed in collaboration with industry, academia, government, and consultant representatives. The plans assess the status of the various technologies for heavy vehicles, develop goals, identify barriers, develop an approach to overcoming the barriers, prioritize projected R&D tasks, and estimate task time frames and financial resource requirements. The following lists technical targets from these plans identified for vehicle systems optimization:

- By 2008, develop a 12-kW diesel APU of less than 20 kg and 20 liters.
- By 2010, reduce aerodynamic drag by 15 percent using active devices and tire and mirror modifications.
- By 2010, reduce cooling system size for a Class 7-8 truck by 8 percent while meeting all cooling specifications.

B. *Heavy Vehicle Hybrid Propulsion*

The focus is to develop and validate heavy hybrid propulsion technologies to support advanced heavy hybrid propulsion systems and provide initial support to the 21st CTP goals[1], respectively:

21st CTP. By 2012, develop and demonstrate a heavy hybrid propulsion technology that achieves a 60 percent improvement in fuel economy, on a representative urban driving cycle, while meeting regulated emissions levels for 2007 and thereafter.

AHHPS. Develop cost-effective heavy hybrid components and systems that could contribute to fuel economy improvements of up to 100 percent by

[1] The 21st CTP long-term goal refers to average fuel economy improvement over a wide spectrum of in-use vehicles, including Classes 4 through 8, and a range of drive cycles for those vehicles. FCVT/AHHPS has a technology-based components and propulsion systems goal specific to certain specific vehicle classes and vocations within the overall vehicle fleet addressed by the 21st CTP goal. AHHPS supports the 21st CTP vehicle goal.

2008, for multiple vehicle applications, while meeting year 2010 EPA emissions standards.

3.1.2.6 Strategic Goals

Full achievement of the element performance goals identified in section 3.1.2.5, especially with regard to heavy hybrid propulsion systems, is critically dependent upon the achievement of goals in other sections of this plan. The Electrochemical Energy Storage activity conducts R&D for light-duty passenger vehicles, which forms the basis for AHHPS targets for improvements in battery life, capacity, power, weight, volume, and cost. The Advanced Power Electronics and Electric Machines (PEEM) activity for light-duty passenger vehicles provides the technology baseline for AHHPS targets for reductions in component size, weight, and cost, along with increases in power density, system voltage, and reliability. However, heavy vehicles have special requirements related to higher power levels and greater reliability to meet the longer warranty periods, which will necessitate enhancements to technologies that are used for light-duty passenger vehicles. Of particular importance to heavy vehicles is the cost, because a credible business case will demand that the savings in operating cost (fuel, brake repair, etc.) be greater than the additional cost of hybridization. Therefore, new technologies based upon lower-cost materials and less expensive manufacturing processes are needed. Power electronics control devices with faster semiconductors, advanced DC-DC voltage conversion, higher power density, and power dissipation will be required, necessitating advanced thermal control solutions. Improved electric machines (e.g., permanent magnet motors) could enable lighter, more cost-effective systems with higher efficiency and power density compared with induction motors. Engine technology developed by the Advanced Combustion Engine R&D subprogram will be leveraged where possible. In addition, the need for advanced aftertreatment technology will be determined based on the propulsion system, duty cycle, and 2010 U.S. Environmental Protection Agency emissions standards.

3.1.2.7 Market Challenges and Barriers

The most significant market barriers to the Heavy Vehicle Systems R&D element are:

A. ***Current market conditions.*** The industry is being driven by the need to meet much tighter engine emission regulations, to such an extent that other innovations for improved energy efficiencies are not generally considered high priorities at this time.

B. ***Cost.*** The cost of a new technology used in a vehicular component, even if cost effective from a life-cycle perspective, continues to represent a major barrier to the timely implementation of the technology in the heavy-duty industry. With regards to heavy hybrid propulsion systems, substantial cost reductions on the order of 2-10 times are required for commercial viability.

3.1.2.8 Technical (Non-Market) Challenges/Barriers

The technical barriers to the Heavy Vehicle Systems R&D element include:

C. ***Component and system performance is too low.*** Lower component volumes and weight, plus higher component and system efficiency, reliability, and durability are required to produce marketplace-acceptable performance levels that create clear technical and economic benefits.

D. ***Safety, durability, and reliability.*** Improvements in the safety, durability, and reliability of new technology are being demanded by industry and required by other government agencies. Component durability must be substantially improved to meet the typical 10-15 year, 1,000,000-mile lifetime requirement of the heavy vehicle industry.

E. ***Computational models, design and simulation methodologies.*** Codes for optimizing future designs, and for accurately predicting the component and system efficiencies applicable to advanced heavy vehicle systems on which the technologies are to be applied in a simulated environment, are either not fully developed or not currently available.

F. ***Higher vehicular operational demands.*** Trends toward higher-horsepower engines, along with new technologies for reducing emissions, are substantially increasing heat rejection requirements, while the industry requires maintaining or reducing component space requirements and costs.

3.1.2.9 Strategies for Overcoming Barriers/Challenges

This procedure of validating performance, component robustness, operational reliability, and cost-competitiveness (conducted in conjunction with prominent participants in the heavy vehicle industry through cost-shared R&D with DOE) is the way most likely to provide a basis for timely introduction of a technology into the marketplace and acceptance by industry. Concomitant benchmarked computer modeling and simulation code formulation can be employed for innovative design approaches and technical and cost optimization methodologies. Ultimately, it is the broad application of the technology within the trucking industry that determines the actual level of success of the R&D effort.

3.1.2.10 Tasks

A description of the heavy vehicle optimization tasks, along with estimated duration and barriers is provided in Table 3.1-2.

Table 3.1-2. *Tasks for Heavy Vehicle Optimization*		
Task	**Title**	**Duration & Barriers**
1	***Aerodynamic Drag Reduction-Phase 1*** • Investigate the applicability of CFD to a complete tractor/trailer system • Validate CFD codes using wind tunnel tests • Instrument a tractor/trailer and conduct full-scale on-road testing	84 months Barriers B, D, E, F
	Aerodynamic Drag Reduction-Phase 2 • Explore near-term commercial aerodynamic drag devices • Conduct on-road testing with commercial fleets	36 months Barriers A, B, D, F
	Aerodynamic Drag Reduction-Phase 3 • Apply CFD to innovative drag reduction technologies for heavy-vehicle applications • Perform wind-tunnel testing for validation • Conduct on-road testing	60 months Barriers A, B
	Aerodynamic Drag Reduction–Phase 4 • Apply CFD to underhood and undercarriage air flow for heavy-vehicles • Combine flow fields with thermal models • Perform wind-tunnel and engine cell testing for validation • Conduct-on-road testing	54 months Barriers C, D, E
	Aerodynamic Drag Reduction-Phase 5 • Use CFD to assess the benefits of aero improvements on safety, stability, and braking • Conduct wind-tunnel testing • Perform full-scale tests on instrumented, fully loaded tractor/trailer.	24 months Barriers D, E
2	***Friction and Wear Reduction-Phase 1*** • Identify failure mechanisms in boundary-layer lubrication regime • Characterize the conditions under which the failure occurs by in-situ experiments • Evaluate candidate methodologies to mitigate the failure	78 months Barriers B, D, F
	Friction-Phase 2 • Identify mechanisms responsible for scuffing, galling, and scoring in the mixed-lubrication regime • Develop and apply computational and simulation techniques to predict failure modes • Systematically explore surface modification technologies and lubricant-surface interactions to enhance the durability and reliability of moving parts	72 months Barriers A, B, D, E, F
	Parasitic Energy Loss Reduction–Phase 3 • Computer modeling to identify possible sources of fuel efficiency increases by reduction of friction in moving engine parts • Laboratory bench tests for development and verification of friction reduction strategies • Single cylinder engine tests • Multi-cylinder engine tests	60 months Barriers A, B, D, E
	Friction Reduction in Gears and Drivetrains–Phase 4 • Computer simulation of increased energy efficiencies by advanced surface engineering • Theoretical modeling of scuffing and surface engineering techniques • Laboratory bench tests • Dynamometer testing of components • On-road instrumented vehicle testing	72 months Barriers A, B, D, E

3	***Essential Power Systems-Phase 1*** • Develop the methodology to efficiently manage thermal and electrical systems and the distribution and control of energy on board the heavy vehicle • Design and assemble and bench test • Build and electrify a Class 3-6 truck operating on diesel fuel • Test and validate the projected energy efficiency under realistic conditions on a test track	48 months Barriers A, B, D, F
	EPS-Phase 2 • Extend EPS technologies to medium-duty, light-duty, and other vehicles • Encourage the development of efficient, lightweight auxiliary power units to interface with EPS to reduce idling of heavy vehicles	48 months Barriers A, B, D, F
4	***Off-Highway Systems: Locomotive-Phase 2 (Phase 1 complete)*** • Identify and simulate promising energy-efficiency technologies and emission-reduction strategies • Test on locomotive to verify various promising energy efficiency technologies and emission reduction strategies	12 months Barriers B, D, E
	Off-Highway Equipment-Phase 2 •Test on off-highway vehicle for fuel efficiency under various operating conditions	12 months Barriers B, D
5	***Thermal Control-Phase 1*** • Define operational conditions and demands on the cooling system of a heavy vehicle using EGR to achieve EPA 2007 and 2010 emission requirements Identify candidate technologies to address the cooling requirements	36 months Barriers B, D, F
	Thermal Control-Phase 2 • Apply simulation and modeling to optimize candidate systems. Measure heat transfer characteristics of various media including nanofluids Simulate various cooling strategies in lab • Design and assemble bench prototypes Test bench prototypes Optimize components and packaging	72 months Barriers B, D, E
	Thermal Control-Phase 3 • Install components on full-scale test vehicle • Perform instrumented tests under typical road conditions • Validate models based on instrumented test data • Optimize components using validated codes	24 months Barriers B, D, E
	Thermal Control– Phase 4 • Conduct fleet demonstration in revenue-bearing service	12 months Barriers B, D

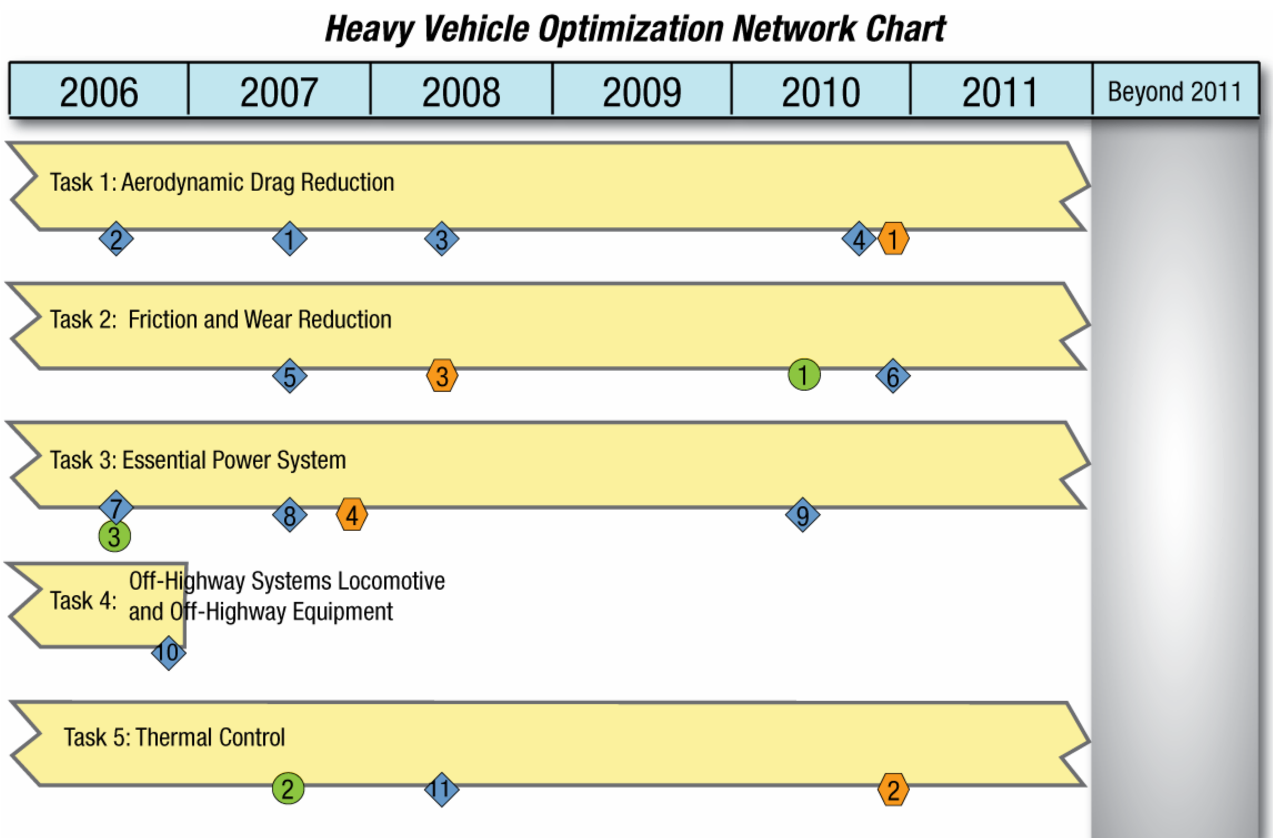
A description of the heavy hybrid propulsion R&D tasks, along with the estimated duration and barriers associated with the tasks, is provided in Table 3.1-3.

Table 3.1-3. *Tasks for Heavy Hybrid Propulsion Systems*

Task	Title	Duration & Barriers
1	Phase I AHHPS Subcontracts	44 months Barriers B, C
2	Phase II AHHPS Subcontracts R&D	12 months Barriers B, C

3.1.2.11 Milestones and Decision Points

Milestones for heavy vehicle optimization and heavy vehicle propulsion systems are shown in the following two network charts.



Legend

Milestone	Technology Program Output	Supporting Input
1. Road test available aerodynamic drag reduction devices 2. Transfer data to computational fluid dynamics team 3. Demonstrate prediction capability with industry partners 4. 15% reduction in aerodynamic drag using active devices 5. Identify candidate methods to mitigate failures 6. Select surface modification technologies and optimized lubricant-surface interactions 7. Electrification of accessory components in Class 8 8. Electrification complete for classes 3-6 9. Class 7/8 truck cooling system 10. Validate systems to increase fuel efficiency 11. Bench-test prototype thermal control	1. Drag reduction technology to AHHPS subcontracts and to industry 2. Thermal control technology to industry 3. Technical data on surface modification technology to reduce friction to Heavy Truck Engine R&D 4. Fuel formulation constraint for APUs to Advanced Fuels R&D	1. Lubricants optimized for use with specific surface modification methods to increase engine efficiency and reduce friction and wear 2. Accurate measurements of increased thermal loading on cooling systems as a result of increased EGR to meet emissions requirements 3. Thermal comfort tools available from Light Vehicle Ancillary Systems R&D

Figure 3.1-3. Network Chart for Heavy Vehicle Optimization

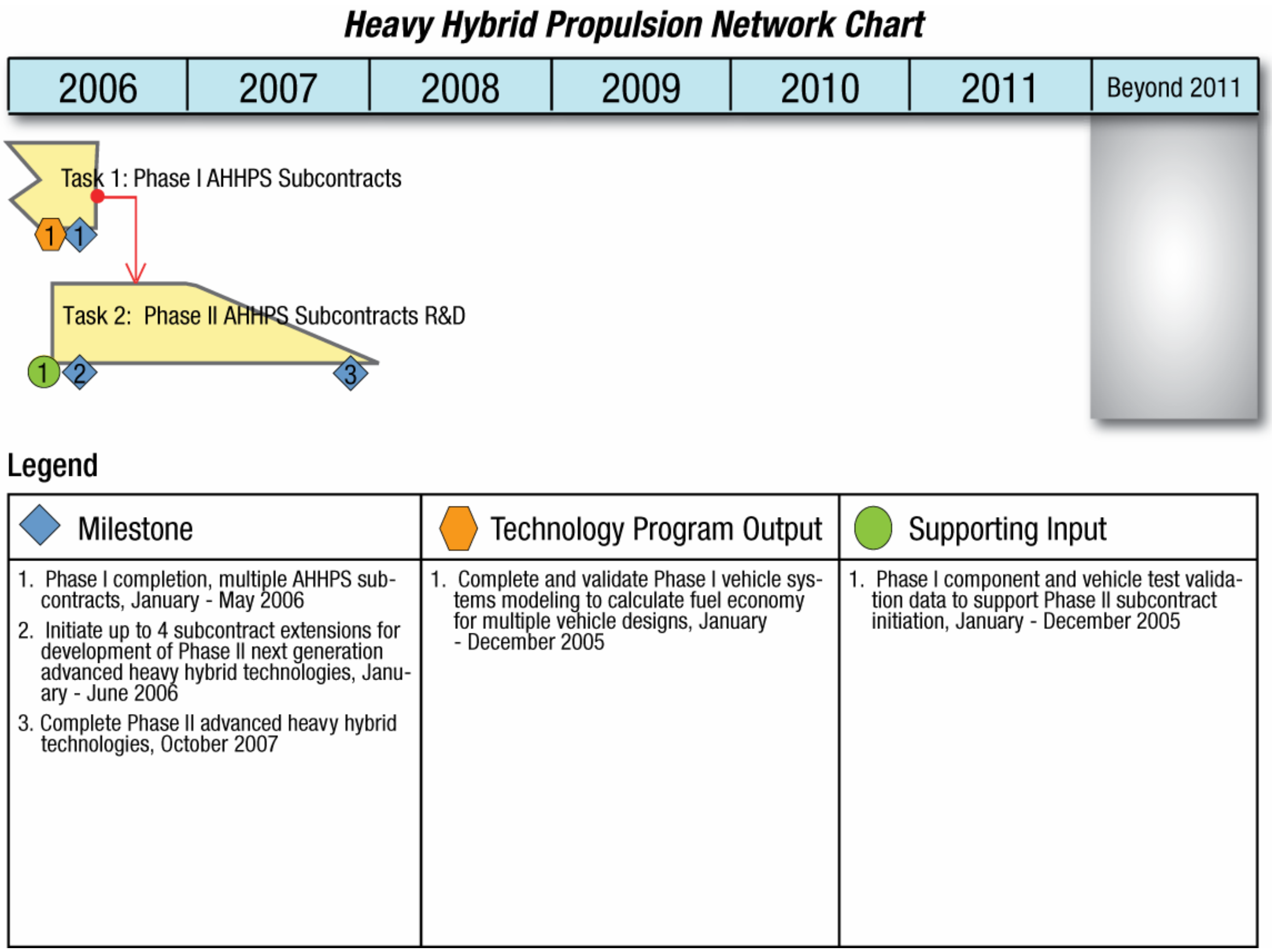


Figure 3.1-4. Network Chart for Heavy Hybrid Propulsion

3.1.3 Light Vehicle Ancillary Systems R&D

3.1.3.1 External Assessment and Market Overview

Ancillary systems impose additional loads on the power source (ICE, hybrid electric vehicle powertrain, or fuel cell vehicle stack) that affect performance, fuel economy, and emissions. The largest ancillary load is the air-conditioning system, which can result in a 4-kW load on the power source. Approximately 7 billion gallons of fuel, equivalent to about 9.5 percent of our imported crude oil, are used to cool light-duty passenger vehicle cabins.

Current fuel economy regulations provide little motivation for automobile manufacturers to reduce the fuel use by air conditioning. In the past, fuel use has not been a primary factor in consumer buying preferences as evidenced by the high sales of large, inefficient vehicles. Fuel savings alone is not sufficient motivation for manufacturers to incorporate fuel-efficient air conditioning systems. Thermal performance in the form of improved human thermal comfort and time to achieve a desired comfort level are essential for motivating manufacturers to incorporate advanced air conditioning systems.

More than half of the fuel used in vehicles is rejected as low-grade waste heat, a potential significant energy source for air-conditioning systems. Reducing the thermal loads and improving delivery of conditioned fluid are essential to the ultimate incorporation of an air conditioning system using waste heat.

3.1.3.2 Internal Assessment and Activity History

Current air-conditioning systems are not optimized to reduce fuel use or use the waste heat energy being rejected from the engine. In Europe, some measures have been taken to reduce air conditioning fuel use due to the cost of fuel. These technologies have not transferred to the U.S. Currently the European Union (EU) is planning to ban the current refrigerant (HFC-134a) and that is providing a unique opportunity in North America to make changes to the air conditioning system. A joint government, industry, and Society of Automotive Engineers (SAE) project called the Improved Mobile Air Conditioning Cooperative Research Project (I-MAC CRP) was formed to determine how environmentally friendly a mobile air conditioning system with the current refrigerant could be. Alternative refrigerant air conditioning systems would have to exceed the performance of the improved system in order to be considered as an acceptable replacement refrigerant. This is an ongoing effort and the project discussed in this section directly supports the I-MAC CRP project.

3.1.3.3 Federal Role

Since current fuel economy regulations provide little motivation for automobile manufacturers to reduce the fuel use by air conditioning, other benefits of fuel-efficient air conditioning systems need to be identified and understood. There is an opportunity for national laboratories to help industry understand other benefits such as improved comfort. Improved thermal performance as well as reduced fuel use will provide incentive for automobile manufacturers to incorporate fuel-efficient air conditioning systems.

Air conditioning systems using waste heat are high risk and face many technical barriers. Automobile manufacturers are not inclined to spend their limited R&D budget in this area. A reduction in the thermal load on the passenger compartment might allow the entire cooling requirements of the vehicle to be met by the waste heat cooling system thereby reducing the energy used for mobile air conditioning (A/C) to zero.

3.1.3.4 Approach

With industry cooperation, ancillary load solutions are developed and tested to reduce fuel use while maintaining occupant comfort. Focus is on complete system integrated modeling, utilization of advanced measurement and assessment tools, and assessment of the potential of a waste heat cabin cooling system.

Measurement and Assessment Tools - An experimental thermal comfort manikin has been developed and is being validated to measure and predict human response to cabin thermal conditions. The manikin will have realistic physical dimensions and weight as well as controllable surface heat output and sweating rate and breathes warm humid air.

Integrated Modeling - The integrated modeling uses multifaceted numerical tools: vehicle and cabin geometry; cabin thermal properties; cabin air velocity and temperature field; and A/C, thermal comfort, and vehicle models. The objective is to integrate all the factors that impact climate control systems to determine their impact on vehicle fuel economy, tailpipe emissions, and the occupants' response to the thermal environment.

Advanced Climate Control System Assessment – The thermal comfort and integrated modeling tools will be used to assess the level of development of advanced climate control systems for advanced vehicles, such as a fuel cell vehicle. Prototype systems will be developed and tested in the Vehicle Climate Control Laboratory and results will be incorporated into the cooling system integrated modeling tool.

Waste Heat Cabin Cooling Evaluation - The goal is to evaluate the potential, as well as technical barriers to the use of waste heat (coolant and exhaust for ICE) to provide cabin cooling and heating. The challenge is incorporating this approach into HEVs which utilize engine off strategies as well as in fuel cell vehicles that have little waste heat. Benchtop testing will validate the technical feasibility of prototypes. Manufacturers will be encouraged to incorporate the most promising technologies into a vehicle.

3.1.3.5 Performance Goals

By 2007 evaluate and report on the state of development and the potential of a waste heat cooling system capable of achieving a coefficient of performance (COP) of 0.5.

3.1.3.6 Strategic Goals

The overall goal of this sub-activity is to enhance U.S. energy security by reducing the fuel used by light-duty vehicle ancillary systems by 50 percent.

3.1.3.7 Market Challenges and Barriers

A. *Higher cost of low energy climate control systems.*

3.1.3.8 Technical (Non-Market) Challenges/Barriers

B. *Barriers to developing cabin-cooling technologies from waste heat include:* relatively low and variable temperatures particularly in fuel cell vehicle applications, weight, volume, corrosion, and engine backpressure and pumping requirements.

C. *Lack of a validated and industry accepted measurement tool to assess human comfort.*

3.1.3.9 Strategies for Overcoming Barriers/Challenges

- In concert with industry, utilize system integrated modeling, advanced measurement and assessment tools, and the development of a waste heat cabin cooling system to reduce fuel use while maintaining occupant comfort. By 2007, these activities will be transitioned to laboratory work-for-others or non-government funded industry projects.

3.1.3.10 Tasks

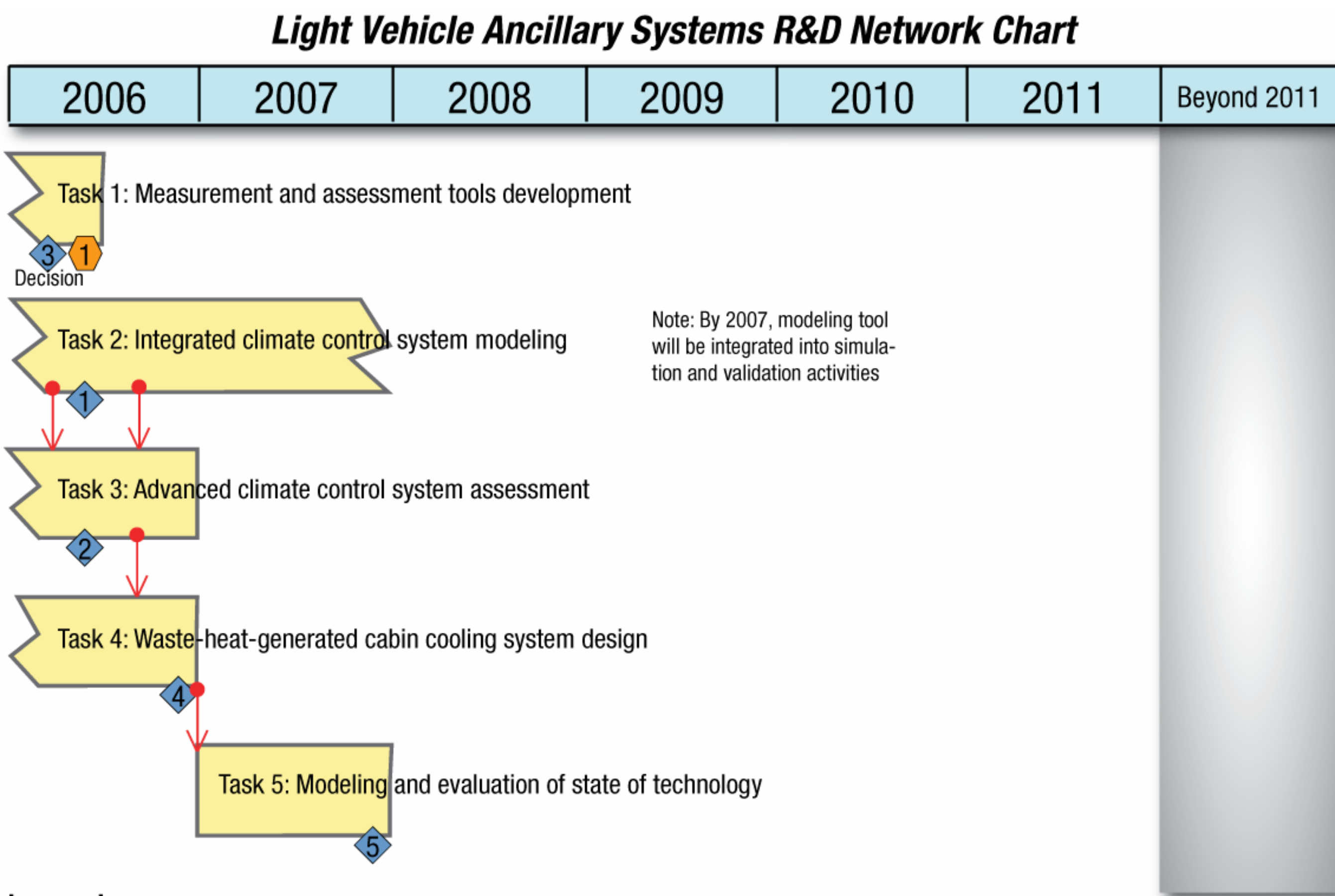
A description of the tasks, along with the estimated duration and barriers associated with the tasks, is provided in Table 3.1-4.

Table 3.1-4. *Tasks for Light Vehicle Ancillary Systems*

Task	Title	Duration & Barriers
1	Measurement and assessment tools development	30 months Barrier C
2	Integrated climate control system modeling to support reduced fuel use for ancillary loads	48 months Barrier A
3	Advanced Climate control system assessment	36 months Barrier A
4	Waste-heat-generated cabin cooling system evaluation	36 months Barrier B
5	Modeling and evaluation of state of technology	12 months Barriers A, B

3.1.3.11 Milestones & Decision Points

Light Vehicle Ancillary Systems activity milestones are shown in the following chart.



Legend

Milestone	Milestone	Technology Program Output
1. Validate integrated systems model 2. Available prototype system incorporated into cooling system integrated modeling tool to assess state of development of advanced climate control systems 3. **Decision.** Based on industry feedback, determine future of current thermal comfort tools	4. Feasibility review of waste heat utilization systems 5. Final report evaluating developed hardware, state of technologies and feasible improvements, and impacts on efficiency	1. Thermal comfort tools available (to Heavy Vehicle Systems Optimization)

Figure 3.1-5. Network Chart for Light Vehicle Ancillary Systems R&D

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