4.2 ADVANCED PROPULSION AND VEHICLE EFFICIENCY IMPROVEMENTS

The Advanced Propulsion and Vehicle Efficiency Improvements sub-program has the vision of improving vehicle fuel economy while meeting future emissions regulations. Figure 15 shows the light-duty and heavy-duty vehicle activities and technology outputs for this sub-program and the collaboration between this sub-program and others. Development technologies for both light and heavy vehicles focus on increasing propulsion system efficiency, improving vehicle energy management and utilization, and decreasing parasitic losses. However, vehicle usage patterns, technical requirements, and commercial markets differ substantially; and the technologies have different industry partners. Hence light-and heavy-duty technology development are presented separately. A common thread running through all light- and heavy-duty technology development is the requirement to view and design for the overall vehicle system to capture the system efficiency and energy management gains possible.

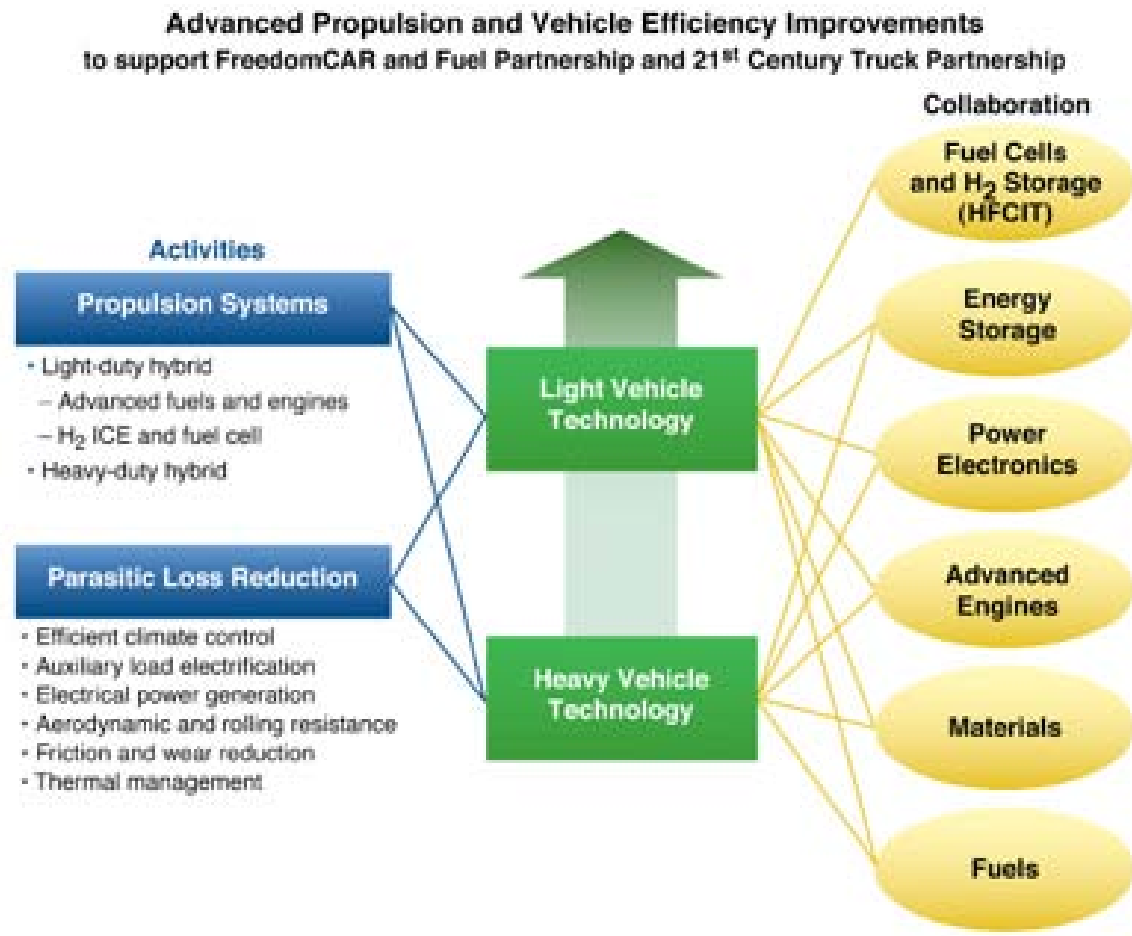


Figure 15. Light-duty and heavy-duty vehicle sub-activities and technology outputs and collaboration between this and other activities.

4.2.1 Light Hybrid Propulsion Systems

Goals

Integrate and develop propulsion system technology developed by DOE and industry partners to achieve the technical targets of the FreedomCAR and Fuel Partnership and support the transition to hydrogen technology.

Programmatic Status

Advanced propulsion system development in FCVT has focused on hybrid technology and conventional fuels. The demonstrated fuel economy improvements and the experience gained in this activity were factors in decisions by DOE's automotive industry partners to introduce production hybrid vehicles by 2004. DOE's analytical and testing capabilities at the national laboratories have evolved substantially as well. Candidate technologies can now be analyzed and tested using HIL techniques in virtual vehicle environments (i.e., testing how a component will interact with other components and will perform in a vehicle on-road, without building and testing a complete vehicle). This capability is currently being used to understand the relationship between fuel economy, emissions, and control strategy in hybrid propulsion systems to minimize the fuel economy penalty of emissions control.

Targets

- By 2010, develop an internal combustion engine (ICE) powertrain system with peak brake efficiency of 45% that is estimated to cost $30/kW.
- By 2010 and 2015, develop hydrogen ICE powertrain systems with peak brake efficiency of 45% that are estimated to cost $45/kW and $30/kW, respectively.

Integrate and test the fuel and propulsion system combinations in the FCVT hydrogen technology transition concept (as the technology becomes available) to quantify the potential contributions to DOE/EERE goals:

- Diesel fuel, ICE hybrid with advanced power electronics and energy storage
- Transitional liquid, advanced ICE hybrid
- Hydrogen fuel, advanced ICE hybrid
- Hydrogen fuel, hybrid fuel cell

As Figure 16 implies, achieving targets for an integrated system depends on receiving subsystems from FCVT technology development areas (represented by the diagrams and detailed in Sections 4.2–4.7) and, sometime in the future, receiving fuel cell-and hydrogen-related subsystems from HFCIT or DOE subcontractors.

Barriers

Technical barriers for components/subsystems are listed in the appropriate sections. The barriers presented here are system-level issues that cannot be addressed solely by analysis.

A. Powertrain system emissions due to engine warm-up and transient demands.

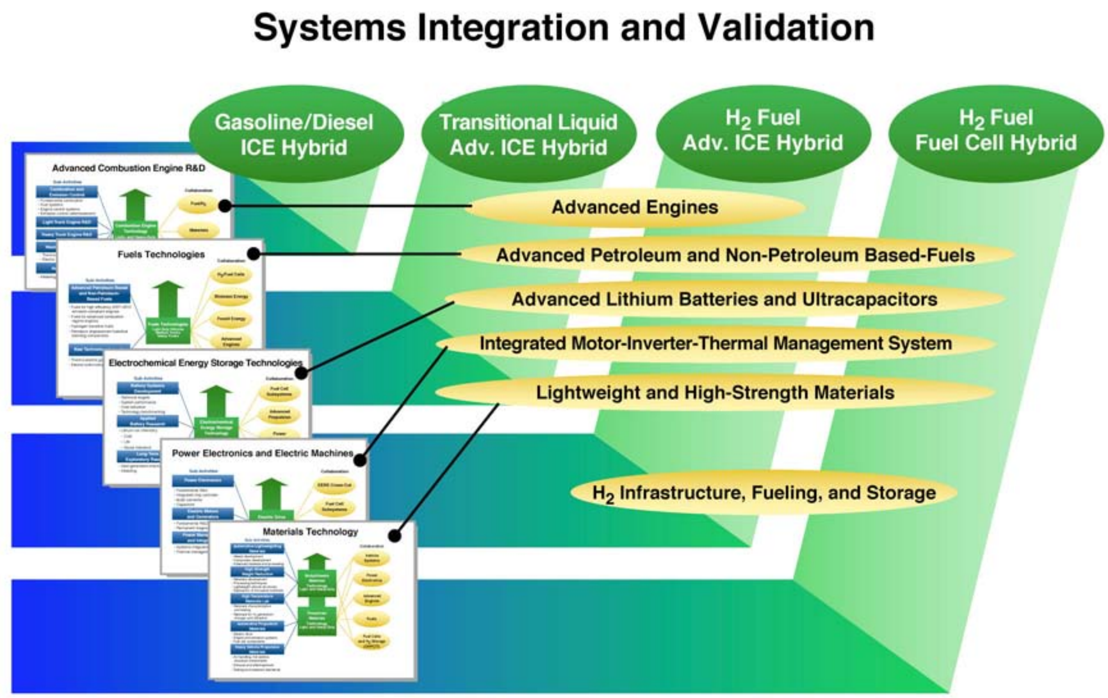


Figure 16. Reaching targets for an integrated system depends on receiving subsystems from FCVT sub-programs, HFCIT, and subcontractors.

B. Determination of hybrid fuel cell system interface, hydrogen fueling, and storage requirements without fuel cell system components.
C. Undefined research protocols and standards for advanced propulsion systems/fuels.

Approach

The transition to hydrogen vehicle technology requires development of the vehicle components, subsystems, and support systems, as well as the infrastructure. The transition concept described previously suggests combinations of fuels and propulsion systems be explored to get the most out of hybrid propulsion systems and gain experience with hydrogen technology while hybrid fuel cell systems are being developed (briefly described in the following paragraphs). Computer modeling, simulation, and analysis of advanced components, systems, and vehicles is needed to ensure that the various fuels, powertrains, and components being developed by FCVT R&D are capable of being integrated into a complete vehicle that achieves marked efficiency improvements compared with current vehicles. In addition, this analysis work will validate that these technologies coming from FCVT R&D activities represent significant technology advances and not merely incremental improvements to currently available technology. Advanced vehicle and component validation, through a combination of laboratory and field testing and evaluation, is also a necessary component to the success of the FCVT initiatives. Not only will this testing and evaluation work provide data needed for the enhanced computer modeling software described above, but also it validates the capabilities of technologies coming from FCVT R&D activities against established technology goals and provides a baseline of performance and capabilities essential to establishing new technology goals or evaluating the adequacy of existing technology goals. To complete these important activities, the computer modeling and simulation tools and the testing and evaluation capabilities and procedures at DOE's national laboratories will be enhanced. These enhancements will be made to simulation tools, component/subsystem integration models, HIL and four-wheel dynamometer laboratory testing, and vehicle-level on-road testing and validation.

Computer simulations will be run annually for the following four technology steps, and the technologies will be evaluated in either component or vehicular applications as they are developed and provided by the FCVT sub-programs.

Gasoline/diesel fuel, ICE hybrid—Apply DOE-sponsored advancements in power electronics, energy storage, aftertreatment, and control to improve efficiency and minimize the emissions control penalty.

Transitional liquid fuel, advanced ICE hybrid—Find fuel formulations to increase hydrogen content and find advanced combustion technology to improve hybrid system efficiency and meet emissions requirements.

Hydrogen fuel, advanced ICE hybrid—Assess hydrogen hybrid propulsion potential and support planning/development/implementation of fueling and storage for vehicle applications (with HFCIT).

Hydrogen fuel, hybrid fuel cell system—Develop hybrid fuel cell system benefits from previous developments in energy storage and electric drive technologies, as well as hydrogen infrastructure planning/development (with HFCIT).

Task Descriptions

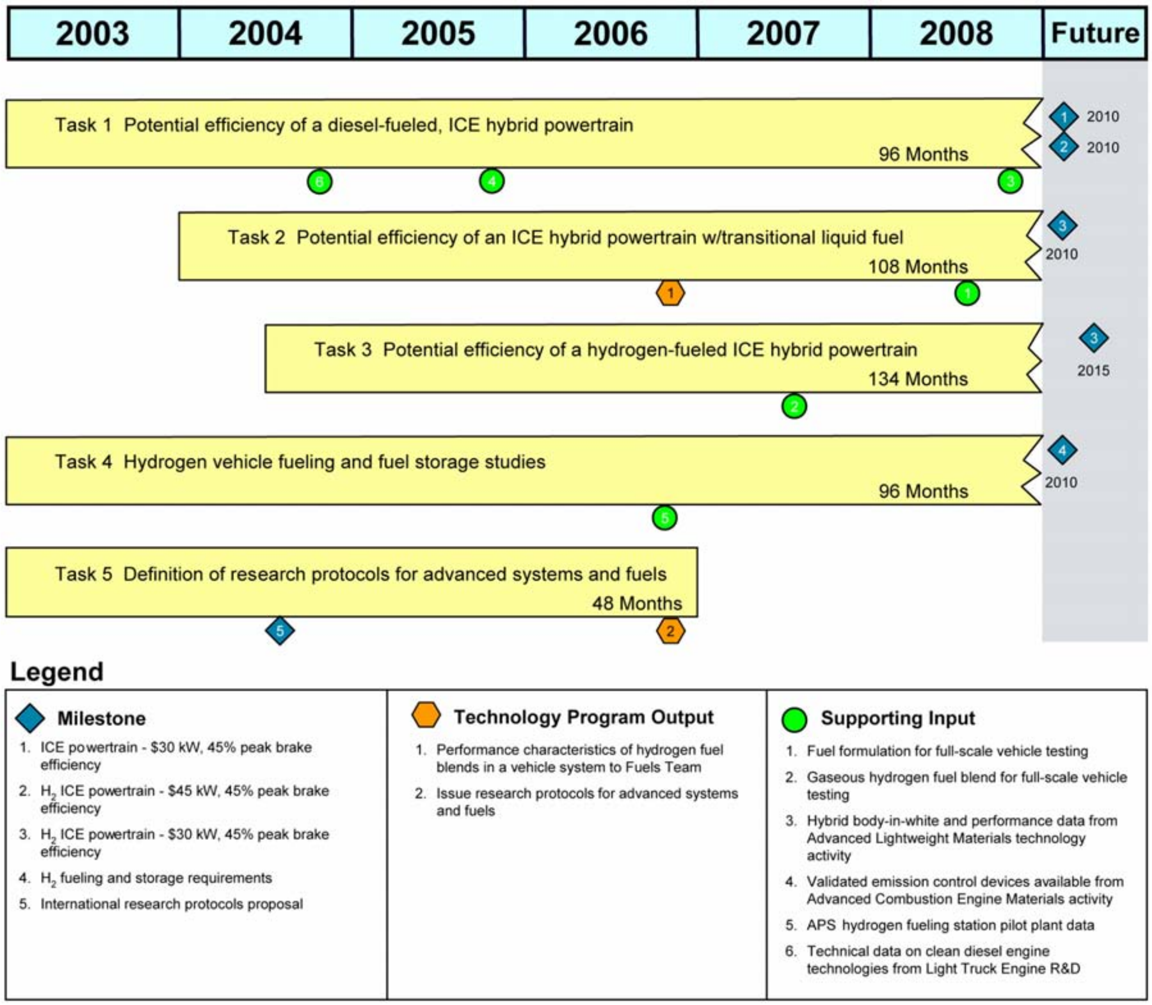
A description of the tasks, along with the estimated duration and barriers associated with the tasks, is provided in Table 2.

Table 2. Tasks for Light Hybrid Propulsion Systems

Task	Title	Duration/ barriers
1	Potential efficiency of a diesel-fueled, ICE hybrid powertrain	96 months Barrier A
2	Potential efficiency of an ICE hybrid powertrain w/transitional liquid fuel	108 months Barrier A
3	Potential efficiency of a hydrogen-fueled ICE hybrid powertrain	134 months Barrier A
4	Hydrogen vehicle fueling and fuel storage studies	96 months Barrier B
5	Definition of research protocols for advanced systems and fuels	48 months Barrier C

Milestones

The network chart shows milestones for Light Hybrid Propulsion Systems.



4.2.2 Heavy Hybrid Propulsion Systems

Goals

Develop and validate heavy hybrid propulsion technologies to support Advanced Heavy Hybrid Propulsion Systems (AHHPS) and 21st CTP goals:[1]

> 21st CTP—By 2012, develop and demonstrate a heavy hybrid propulsion technology that achieves a 60% 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% by 2008, for

[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. 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, and it supports the long-term 21st CTP vehicle goal.

multiple vehicle applications, while meeting year 2007 EPA emissions standards.

Full achievement of the goals is critically dependent upon the achievement of goals in other sections of this plan, such as in Section 4.3, to advance the energy storage technology.

Programmatic Status

DOE has awarded three Phase I AHHPS subcontracts for R&D on advanced heavy hybrid propulsion components and systems for a range of vehicle applications (Class 3 through 8 trucks and buses).

Hybrid electric propulsion components and systems are highly developed for light-duty vehicles, but the technology requires further development for heavy hybrid vehicle applications. Components for heavy vehicles either do not exist or cost too much because of precision manufacturing and/or low production volumes. In addition, component durability must be substantially improved to meet the typical 10–15 year, 1,000,000-mile lifetime requirement of the heavy vehicle industry.

Although modeling, simulation, and optimization for Class 3–8 hybrid vehicles have represented less than 10% of the previous FCVT modeling efforts, the mature light-duty vehicle models FCVT developed are now the focus of enhancement efforts to provide simulation and modeling capabilities for Class 3–8 vehicles. Component and system-level technical targets are being analyzed and established as part of the AHHPS activity. System-level modeling and optimization tools will require some adaptation to accommodate heavy vehicle components in order to configure propulsion systems and identify control strategies with the potential to meet the heavy vehicle fuel savings goal.

Targets

Preliminary technical targets, shown in Table 3, have been identified by the industry development teams, but they are expected to be modified as detailed analyses are completed and AHHPS developments mature.

Barriers

The technical barriers to achieving AHHPS goals are as follows:

A. **Initial and life-cycle component costs are too high.** Substantial reductions are required to make costs competitive for vehicle commercial viability.

B. **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.

C. **Heavy hybrid test procedures are not available.** Current 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 hybridization technology.

	Vehicle system	2003	2006	2010
Propulsion				
	Peak specific power (kW/kg)	0.5–0.6	0.8	0.8
	Weight (kg/kW)	1.6–2.0	1.25	1.25
	Volume (m^3/W)	0.0018	0.0014	0.0014
	Cost ($/kW)	1000	100–400	42
Engine				
	Power (kW)	TBD	TBD	TBD
	Brake thermal efficiency		45%	50%
	Specific power (kW/kg)	TBD	TBD	TBD
Energy Storage				
	Discharge power (kW)	25–75	50–150	50–150
	Weight (kg/kW)	1.5	1.0	1.0
	Volume (m^3/kW)	0.00175	0.00175	0.00175
	Cost ($)	2500	1000	1000
	Specific power (W/kg)	650	1000	1000
	Specific energy (W·h/kg)	30	40	40
Power Electronics				
	Operating voltage (V)	200–600	200–600	200–600
	Power (kW)	50–150	50–150	50–150
	Lifetime (years)	<5	15	15
	Cost ($/kW)	115	20–30	8
	Specific power (kW/kg)	2–3	4–4.5	5–6
	Efficiency	97–98	97–98	TBD
Regenerative Braking				
	Efficiency	30%	30%	50%
Auxiliary Electric Power				
	Average/peak power (kW)	3–5/8–10	5–10/10–30	5–10/10–30

[a] Preliminary estimates by industry teams are subject to change

Approach

The three AHHPS industry teams are analyzing a range of heavy hybrid vehicles, including Class 3–8 trucks and buses, to define system architecture, optimize control strategy, and quantify component requirements. Engine subsystems, energy storage, power electronics, controls, and auxiliary power units (APUs) will subsequently be developed to meet the requirements. The teams will also design, integrate, and validate complete vehicle systems using heavy hybrid test procedures and protocols developed within the time frame of the tasks. AHHPS preliminary technology development targets are identified in Table 3, and relevant FCVT targets for R&D coordination are identified in the following text.

Engine technology developed by the Advanced Combustion Engine R&D sub-program will be leveraged where possible. Particular attention will focus on the interface requirements for hybrid system components (i.e., electric motors and/or generators, energy storage, electric auxiliaries, and control systems). In addition, the need for advanced aftertreatment technology will be determined based on the propulsion system, duty cycle, and 2007 U.S. Environmental Protection Agency (EPA) emissions standards.

The Electrochemical Energy Storage sub-program conducts R&D for light-duty vehicles that forms the basis for AHHPS targets for improvements in battery life, capacity, power, weight, volume, and cost.

The Advanced Power Electronics and Electric Machines sub-program for light-duty 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. Power electronics control devices with faster semiconductors, advanced dc-to-dc conversion, higher power density, and power dissipation will be required, necessitating advanced thermal management 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.

The system architectures envisioned require high-grade electrical power to charge energy storage systems and to run electric auxiliary components. An integrated approach to supply this power will be considered, including regenerative braking, APUs, and waste heat recovery systems.

A systematic approach to component and system requirements necessitates modeling and optimization. ADVISOR integrated modeling and optimization techniques will be provided for the vehicle, powertrain, energy storage and management, power electronics, auxiliary loads, and regenerative braking. In addition, industry teams will use proprietary models as well as PSAT for detailed design and control analysis. The AHHPS activity is using vehicle systems technical target tools developed in vehicle systems analysis tasks to establish AHHPS technical targets. The AHHPS activity is also integrating relevant task results and coordinating appropriate cross-linked R&D tasks discussed in Sections 4.1, 4.3, 4.4, and 4.5.

Heavy hybrid vehicle testing is expected to begin in FY 2005 and will use national laboratory facilities. Hybrid vehicle testing results will validate heavy hybrid technologies to ensure they are ready for technical and economic commercialization, as well as validate AHHPS and industry vehicle models.

Task Descriptions

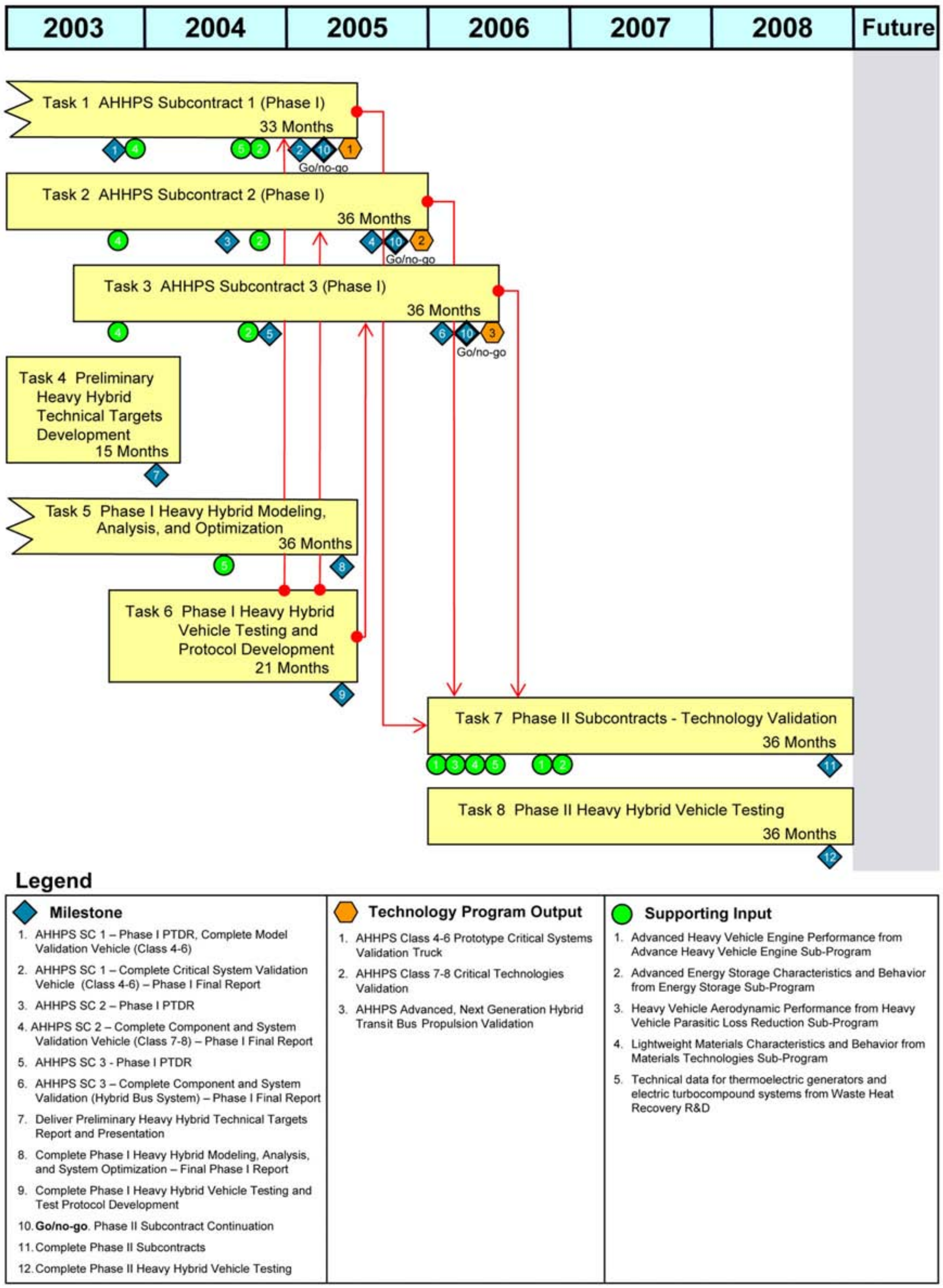
A description of the tasks, along with the estimated duration and barriers associated with the tasks, is provided in Table 4.

Table 4. Tasks for Heavy Hybrid Propulsion Systems

Task	Title	Duration/ barriers
1	AHHPS Subcontract 1 (Phase I) • Advanced Parallel Hybrid Propulsion System • Class 4–6 Heavy Hybrid Vehicle	33 months Barriers A,B,C
2	AHHPS Subcontract 2 (Phase I) • Advanced Series Hybrid Propulsion System • Class 7–8 Heavy Hybrid Vehicle	36 months Barriers A,B,C
3	AHHPS Subcontract 3 (Phase I) • Advanced Parallel Hybrid Propulsion System • Class 7 Heavy Hybrid Bus	36 months Barriers A,B,C
4	Preliminary Heavy Hybrid Technical Targets Development	15 months Barrier A,B
5	Phase I Heavy Hybrid Modeling, Analysis, and Optimization	36 months/ Barrier B
6	Phase I Heavy Hybrid Vehicle Testing and Protocol Development	21 months Barrier C
7	Phase II Subcontracts—Technology Validation	36 months Barriers A,B,C
8	Phase II Heavy Hybrid Vehicle Testing	36 months Barriers A,B,C

Milestones

Heavy Hybrid Propulsion System activity milestones are provided in the following network chart.



4.2.3 Light Vehicle Ancillary Systems

Goals

The overall goal of this activity is to reduce the fuel used by light-duty vehicle ancillary systems by 5 billion gallons annually by 2010.

Programmatic Status

Ancillary systems impose additional loads on the power source [ICE, fuel cell stack, or hybrid electric vehicle (HEV) powertrain] 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. About 7 billion gallons of fuel, equivalent to about 9.5% of our imported crude oil, are used annually to cool light-duty vehicle cabins. Current air-conditioning systems are not optimized to reduce fuel use or use the waste heat energy being rejected from the engine. 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.

Targets

- By 2005 and 2010, demonstrate air-conditioning systems that reduce energy consumption by 50% and 75%, respectively, relative to current technology.
- By 2012, demonstrate a waste heat cooling system capable of achieving a coefficient of performance of 0.5.
- By 2012, demonstrate a reduced-energy-use ancillary load system in a concept car.

Barriers

A. Higher cost of low-energy climate control systems.
B. Developing cabin-cooling technologies from waste heat: relatively low and variable temperatures, particularly in hybrid fuel cell vehicle applications; weight; volume; corrosion; and engine backpressure and pumping requirements.
C. Lack of a measurement tool to assess human comfort.

Approach

With industry cooperation, develop and test ancillary load solutions to reduce fuel use while maintaining occupant comfort. The focus is on complete system integrated modeling, use of advanced measurement and assessment tools, and development of a waste heat cabin cooling system. Reducing the energy usage for heating as well as cooling will be considered. Turning low-grade heat energy into useful energy is a priority. An experimental thermal comfort tool is being developed and will be validated to measure and predict human response to cabin thermal conditions. This tool will have realistic physical dimensions and weight as well as the ability to control surface heat output, control its sweating rate, and breathe warm, humid air. The approach to the integrated modeling is to simulate all the climate control and ancillary systems to determine their impact on vehicle fuel economy, tailpipe emissions, and the occupants' response to the thermal environment

Task Descriptions

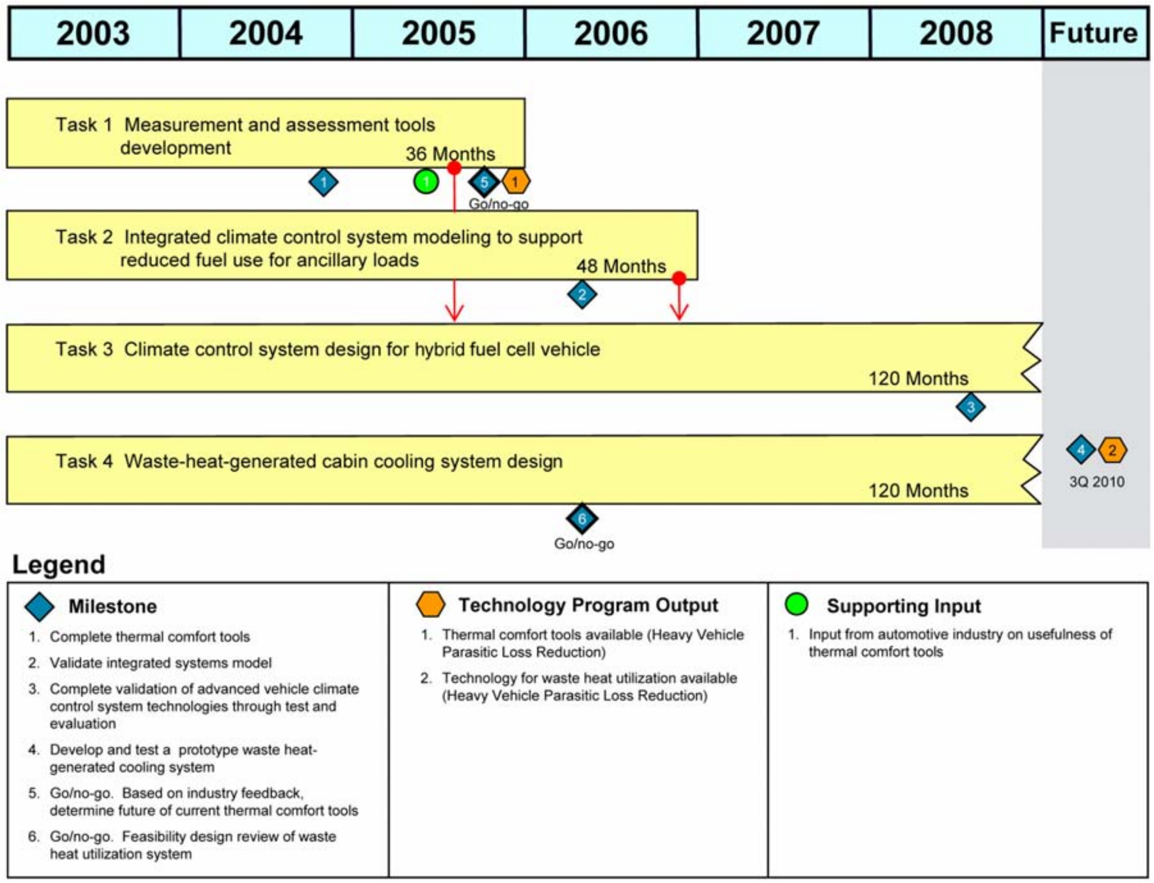
A description of the tasks, along with the estimated duration and barriers associated with the tasks, is provided in Table 5.

Table 5. Tasks for Light Vehicle Ancillary Systems

Task	Title	Duration/ Barriers
1	Measurement and assessment tools development	36 months Barrier C
2	Integrated climate control system modeling to support reduced fuel use for ancillary loads	48 months Barrier A
3	Climate control system design for hybrid fuel cell vehicle	120 months Barrier A
4	Waste-heat-generated cabin cooling system design	120 months Barrier B

Milestones

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



4.2.4 Heavy Vehicle Parasitic Loss Reduction

The purpose of this activity is heavy vehicle optimization to identify and develop technologies and components that reduce the parasitic energy losses of heavy vehicles. When parasitic energy losses are reduced, less energy is required to operate a heavy vehicle performing the same amount of useful work, translating into greater energy efficiency for the vehicle and thus the entire truck fleet. All parasitic energy losses except those due to the vehicle weight are addressed in this activity, including aerodynamic drag, rolling resistance, friction and wear, thermal loads, and idling losses. The energy losses due to weight are addressed in the High Strength Weight Reduction Materials activity.

Goals

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% of total engine output in 1998 to 24% in 2006. (This is a priority FCVT goal identified in Section 3.)

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

- Develop and demonstrate advanced technology concepts that reduce the aerodynamic drag of a Class 8 highway tractor-trailer combination by 20% (from a current average drag coefficient of 0.625 to 0.5).
- Develop and demonstrate technologies that reduce essential auxiliary loads by 50% (from the current 20 horsepower to 10 horsepower) for Class 8 tractor-trailers.
- Reduce the weight of a tractor-trailer from 23,000 lb in 2003 to 18,000 lb in 2010 (a 22% reduction).
- 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 (on-board) and truck stop (stationary) electrification technologies to enable the introduction of new idle-reduction technologies.

Programmatic Status

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. This approach facilitated the development of a national agenda for a coordinated R&D effort to achieve the stated goals that is industry-relevant and simultaneously responsive to the broader needs of the nation. A final plan in each technical area was published and broadly circulated to the technical community, especially within the heavy vehicle industry. In conjunction with the research tasks undertaken, computational models and simulation programs are being developed simultaneously and being used to predict the fuel economy implications of applying the candidate technologies.

Targets

- By 2004, demonstrate an 8% increase in fuel economy from electrification of accessory components.
- By 2005, produce a 5% reduction in aerodynamic drag coefficient.
- By 2008, develop a 12-kW diesel APU of less than 20 kg and 20 liters.
- By 2010, reduce aerodynamic drag by 15% using active devices and tire and mirror modifications.
- By 2010, reduce cooling system size for a Class 7-8 truck by 8% while meeting all cooling specifications.
- By 2015, develop system improvements and control strategies to improve the efficiency of railroad locomotives by 8%.

Barriers

Barriers common to all technology development tasks:

A. **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.

B. **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.

C. **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.

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

E. **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.

Approach

To accomplish the goals of this technology development activity, the methodologies identified to achieve the reductions in energy losses must be developed and tested in the laboratory. They must then be prototyped and tested onboard a heavy vehicle. Subsequent to technology validation, on-road data must be accumulated to determine the durability, reliability, and life-cycle cost data of the developmental component and/or design strategy. It is axiomatic in the heavy 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. Concomitant benchmarked computer modeling and simulation code formulation can then be employed for innovative design approaches and technical and cost optimization methodologies. 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 process most likely to provide a basis for timely introduction of a technology into the marketplace and acceptance by industry. 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.

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% 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% reduction in drag will result in a 25% 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. A flagship aerodynamic phenomenon known as the Coanda effect has led to breakthrough concepts in the effort to render heavy-duty long-haul Class 7 and 8 trucks substantially more energy- and cost-efficient.

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 data.

Development of innovative concepts will continue, including formulation of codes based on vorticity rather than conventional grid elements. An acoustic spoiler and a pneumatic drag reduction device, which can also increase tractor-trailer stability and improve braking, will be characterized.

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 silicon/silicon carbide 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.

Friction and wear reduction. 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 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 are part of a systems approach to using on-board energy efficiently. Within the EPS approach, concepts to reduce energy losses will include diesel APUs; 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% greater energy efficiency. Further, this systematic approach to energy management enables an effective way of reducing the need to idle the heavy-duty tractor engine to heat or cool the cab/sleeper or heat the engine block, fuel, and oil (in winter) during idling hours. This could save up to 1.5% of the total fuel use in the surface transport sector.

Regenerative shocks. A regenerative shock-absorbing device consisting of a permanent magnet and a copper coil will be used to recover a substantial fraction of energy otherwise dissipated in conventional shock absorbers. Theoretical calculations will be compared with results from tests on a simple experimental system. A decision to proceed to additional scale-up and system complexity will be based on the comparative results from these tests. It is likely that these devices will also be applicable to railroad rolling stock, where electrification of brake actuating systems is being examined by the U.S. Department of Transportation and the rail industry.

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%. 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.

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 to heat the cab/sleeper, but few are addressed to cooling it. These products, plus the EPS and truck electrification technologies that DOE and industry are developing, enable nearly complete idling elimination. Only about 1% of U.S. trucks are outfitted with the idle-reduction devices, while the equipment is carried by 70% 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 truck shows and meetings at a DOE/FCVT booth. It is estimated that full penetration of idling-reduction devices in the long-haul truck fleet could save up to 1.5% 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.

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 autothermal 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 management. 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% 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 management 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 three-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%, despite the increased heat rejection requirements due to the EGR approach.

Task Descriptions

A description of the tasks, along with the associated estimated durations and barriers, is provided in Table 6.

Table 6. Tasks for Heavy Vehicle Parasitic Loss Reduction

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	60 months Barriers A, C, D, E
	Aerodynamic Drag Reduction—Phase 2 • Explore near-term commercial aerodynamic drag devices • Conduct on-road testing with commercial fleets	36 months Barriers A, B, C, E
	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 *(begin 3Q 2005)*
	Aerodynamic Drag Reduction—Phase 4 • 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	52 months Barriers C, 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	48 months Barriers A, C, D, E
	Friction—Phase 2 • Identify mechanisms responsible for scuffing, galling, and scoring in the mixed-lubrication regime. • Develop and apply computation 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, C, 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 • Assemble a prototype vehicle • Test and validate the projected energy efficiency of a prototypic vehicle under realistic conditions on a test track	48 months Barriers A, B, C, E
	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, C, E
4	Regenerative Shocks—Phase 1 • Using actual highway profiles, calculate potential energy recovery • Construct a prototype device • Bench-test a prototype device • Optimize the design of the prototype	60 months Barriers A, D, E
	Regenerative Shocks—Phase 2 • Assemble on the prototype light test vehicle • Conduct road tests to determine recoverable energy • Determine the feasibility of transferring the technology to heavy vehicles	44 months Barriers A, D, E

Table 6. Tasks for Heavy Vehicle Parasitic Loss Reduction

Task	Title	Duration/ barriers
5	Off-Highway Systems: Locomotive—Phase 1 • Identify and simulate promising energy-efficiency technologies and emission-reduction strategies • Select candidate technologies • Design and develop bench-test systems • Bench-test technologies • Build and test a prototype vehicle	70 months Barriers A, C, D, E
	Locomotive—Phase 2 • Test on locomotive in various conditions	12 months Barriers A, C, D, E
	Off-Highway Equipment—Phase 1 • Identify and simulate promising energy-efficiency technologies and emission-reduction strategies • Select candidate technologies • Design and develop bench-test systems • Bench-test technologies • Build and test a prototype vehicle	70 months Barriers A, C, D, E
	Off-Highway—Phase 2 • Test on off-highway vehicle under various operating conditions	12 months Barriers A, C, D, E
6	Thermal Management—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	24 months Barriers A, C, D, E
	Thermal Management—Phase 2 • Apply simulation and modeling to optimize candidate systems • Design and assemble bench prototypes • Test bench prototypes • Optimize components and packaging	42 months Barriers A, C, D, E
	Thermal—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 A, C, D, E
	Thermal—Phase 4 • Conduct fleet demonstration in revenue-bearing service	12 months Barriers A, C, D, E

Milestones

Milestones for Heavy Vehicle Parasitic Loss Reduction are shown in the network chart.