4.6 MATERIALS TECHNOLOGIES

The FCVT Materials sub-program aims to develop and validate advanced materials and processing technologies that can lead to achievement of the FreedomCAR and Fuel Partnership and 21st CTP goals. The weight reduction and vehicle system technologies pursued in this sub-program address the critical materials needs for frame, body, chassis, and powertrain systems for cars, light trucks, heavy trucks, and buses. Because of the broad scope of technologies needed to address these varied applications, the sub-program is divided into five activities that focus on a basket of technologies best suited to the appropriate application (Figure 20).

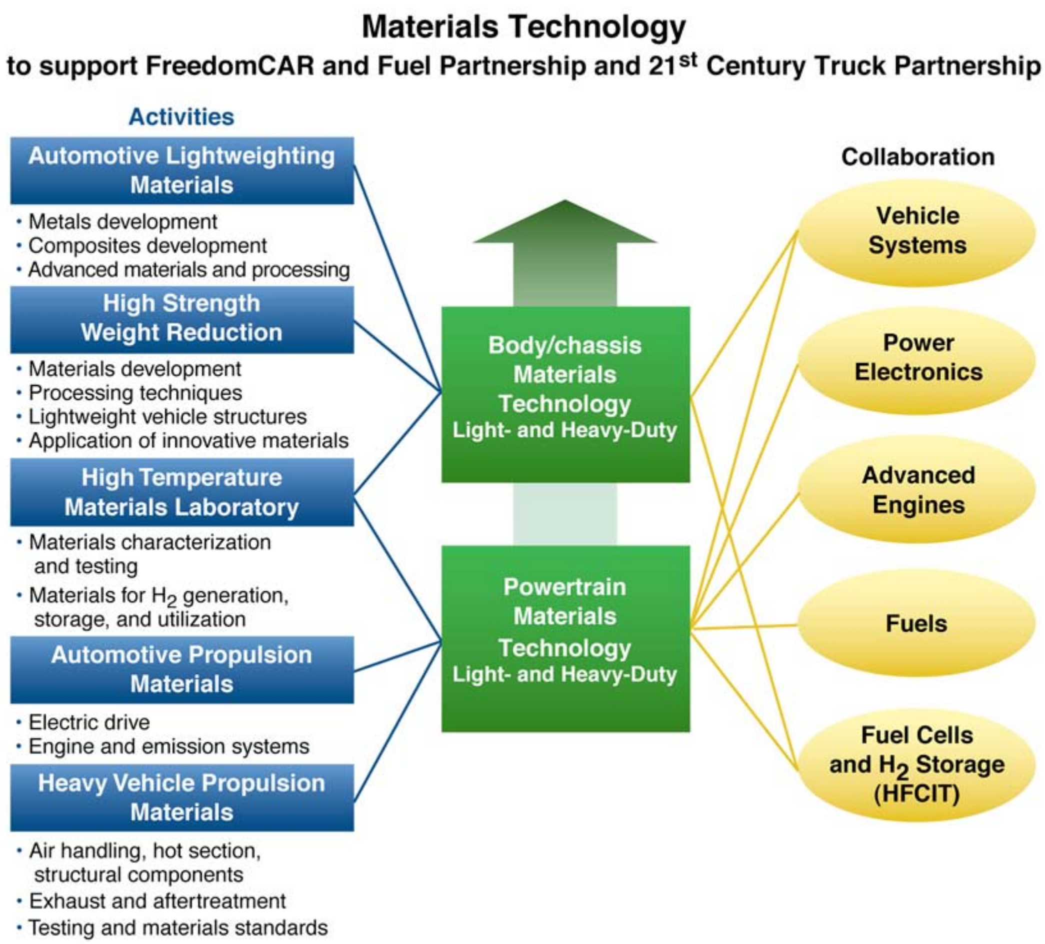


Figure 20. Activities, applications and collaborations in Materials Technologies.

The Automotive Lightweighting Materials (ALM) and Automotive Propulsion Materials (APM) activities interface with the FreedomCAR and Fuel Partnership to establish industry needs. The High Strength Weight Reduction (HSWR) and Heavy Vehicle Propulsion Materials (HPVM) activities interface with the 21st CTP to establish industry needs. The High Temperature Materials Laboratory activity provides critical support to the entire transportation industry for materials research requiring unique characterization equipment. The ALM and HSWR activities are focused on structural materials for body and chassis applications; they collaborate with the Vehicle Systems sub-program and the HFCIT Program to establish requirements. The APM and HVPM activities are focused on powertrain applications and establish their requirements through collaborations with the Power Electronics, Advanced Engines, and Fuels Technologies sub-programs and the HFCIT Program.

The goals, status, technical targets, barriers, and research plans for each of the materials activities are described in the following subsections.

4.6.1 Automotive Lightweighting Materials

The vision of the ALM activity is to develop and validate cost-effective lightweighting materials technologies that could significantly reduce automobile weight without compromising vehicle cost, performance, safety, or recyclability. Research performed under this activity is primarily focused on light vehicle applications; however, it is recognized that the technologies may also have application on heavy vehicles. Management of this activity and the High Strength Weight Reduction activity are coordinated to ensure that they are complementary, rather than duplicative.

Goals

The goals of this activity include the priority FCVT goal identified in Section 3 for the production cost of carbon fiber. In addition, the goals directly support the FreedomCAR and Fuel Partnership goal, "Technology for high-volume production which enables simultaneous attainment of 50% weight reduction of vehicle structure and subsystems, affordability, and increased use of recyclable/renewable materials."

- By 2006, reduce the production cost of carbon fiber from $12 per pound (in 1998) to $3 per pound (at an annual production level of 5 million pounds).
- By 2006, develop and validate advanced material technologies that will
  - Enable significant reductions in the weight of body and chassis components and overall vehicle weight (50% reduction in weight of components and 40% reduction in overall vehicle weight relative to 1997 baseline five-passenger vehicles);
  - Exhibit performance, reliability, and safety characteristics comparable to those of conventional vehicle materials; and
  - Be cost-competitive, on a life-cycle basis, with costs of current materials.
- By 2012, develop and validate advanced material technologies that will
  - Enable reductions in the weight of body and chassis components by at least 60% and overall vehicle weight by 50% (relative to 1997 comparative vehicles);
  - Exhibit performance, reliability, and safety characteristics comparable to those of conventional vehicle materials; and
  - Be cost-competitive, on a life-cycle basis, with costs of current materials.

Programmatic Status

Significant progress has been made in the technologies required to manufacture vehicles that meet the FCVT weight reduction targets. Concept vehicles and vehicle designs by the industry partners are demonstrating that the weight targets are achievable. Unfortunately, the materials and manufacturing costs associated with these vehicles are still too high, so additional R&D is needed to achieve the affordability target of comparable cost with acceptable performance, safety, and recyclability.

The R&D tasks of the ALM activity are being conducted through a variety of contractual mechanisms, including cooperative research and development agreements, cooperative agreements, university grants, subcontracts, and in-house research at national laboratories. Other research partners in these efforts include automotive companies, materials suppliers, and non-profit technology organizations.

To achieve the overall FCVT vehicle-level goals, it is imperative that lighter-weight materials be developed with sufficient strength and stiffness to replace conventional materials (i.e., mild steel) for body and chassis applications. FCVT is addressing these imperatives by developing materials and materials-processing technologies, validating these technologies through representative component prototyping, and developing adequate design data and design methodologies to facilitate their beneficial application.

Targets

The technical targets to be achieved by this activity are listed in Table 31.

Barriers

A. **Cost.** Prohibitively high cost is the greatest single barrier to the viability of advanced lightweight materials for automotive applications.
B. **Manufacturability.** Methods for the cost-competitive, high-volume production of automotive components from advanced lightweight materials do not exist, except for some applications of cast aluminum and magnesium.
C. **Design methodologies.** Adequate design data (material property databases), test methods, analytical tools (i.e., models), and durability data are inadequate for widespread applications of advanced lightweight materials.
D. **Joining.** High-volume, high-yield joining technologies for lightweight and dissimilar materials do not exist.
E. **Recycling and repair.** Technologies for cost-effective recycling and repair of advanced materials, especially carbon-fiber-reinforced composites, do not exist.

Approach

FCVT research is focused on specific classes of materials using representative, nonproprietary components. As technical barriers are removed, the technology will be made available for industry to take in-house to perform proprietary, application-specific research.

Table 31. Technical targets: Automotive Lightweighting Materials			
Characteristics	**Year**		
	2003	**2006**	**2012**
Weight of body in pounds	1250	625[a]	580
Aluminum sheet cost per pound	$1.70	$1.20	$1.20
Aluminum manufacturing and assembly savings relative to steel per body	–$250	–$100	$0
Aluminum body life-cycle cost relative to steel[b]	1.5×	1×	1×
Glass-fiber-reinforced composite body life-cycle cost relative to steel[b]	1.2×	1×	1×
Carbon fiber cost per pound	$8.00	$3.00	$2.50
Carbon composite mfg and assembly savings relative to steel per body	−$300	$0	$100
Carbon-fiber-reinforced composite life-cycle cost relative to steel	3×	2×	1×
Weight of chassis in pounds	940	470	425
Aluminum chassis life-cycle cost relative to steel[b]	1.5×	1×	1×
Glass-fiber-reinforced composite chassis life-cycle cost relative to steel[b]	1.2×	1×	1×
Carbon-fiber-reinforced composite life-cycle cost relative to steel	3×	2×	1×
Weight of propulsion subsystem in pounds[c]	860	775	750
Weight of fuel subsystem in pounds[c]	190	90	85
Total vehicle[a] weight in pounds	3240	1960	1840

[a] P2000 LSR is Ford Motor Company's hybrid electric vehicle delivered to DOE on October 5,1999.
[b] For production volumes greater than 100,000 per year.
[c] The ALM technology area addresses only body and chassis weight; propulsion subsystem and fuel subsystem weight are included for reference only and are addressed elsewhere in the plan.

Lightweighting materials research addresses the five high-priority barriers identified as follows:

A. **Cost reduction.** Technologies will be pursued that are aimed at reducing the cost of manufacturing lighter-weight automotive structural components. These technologies include
   - Carbon fiber—Research will be pursued that seeks to use new classes of precursors and provide the tools for scaling up precursor volumes and that investigates alternate methods for manufacturing carbon fibers in large volumes.
   - Titanium alloys—The use of titanium alloys is limited because of the cost of the raw materials and the costs associated with manufacturing. Research will be conducted in both areas in order to take advantage of the potential of these alloys.
   - Advanced reinforcement development—Many advanced reinforcement technologies have been identified in recent years that offer the potential for providing low-cost polymer-based materials that are easily processable with exceptionally high performance. Research will be conducted to develop these technologies for application in the automotive industry.
   - Primary metal production—Research will focus on the basic methodologies for cost-effectively producing primary light metals (aluminum, magnesium, and titanium) that rely on energy-intensive, costly technologies. Research will identify opportunities for optimizing these technologies to achieve efficiency improvements that will result in lower-cost primary metals.

- Magnesium alloys—The focus of research will be to develop improved alloying strategies for low-cost, creep-resistant magnesium alloys that can be die cast.
- Metal matrix composites (MMCs)—Research opportunities to reduce the cost of reinforcing materials, matrix materials, and preforms will be evaluated.
- Glazing materials— Research will be performed to address issues of safety, abrasion resistance, and light transmissibility for advanced glass materials while simultaneously addressing cost-competitiveness.
- Thermoplastic resin systems—Technologies will be developed for increasing the performance properties of less costly thermoplastic systems by 10–30%.

B. **Manufacturability.** Materials processing technologies will be pursued that yield the required component shapes and properties in a cost-effective, rapid, repeatable, and environmentally conscious manner. These technologies include

- Composite processing—Technologies will be pursued for high-volume production of both thermoplastic and thermoset composite materials. These technologies include but are not limited to high-volume injection molding, injection compression molding, pultrusion, net-shape forming, thermoplastic thermoforming, resin transfer molding, non-thermal curing methods, automated material handling systems, and the development of resin systems more amenable to the automotive industry. High-rate preforming techniques will be developed to obtain chopped-fiber preforms with consistently controlled fiber distribution and density at the volumes required by industry.
- Light metals—Research will focus on processing improvements that result in more-reliable cast components made of magnesium with improved performance capabilities to enable increased use of such components in automotive structural applications. Technologies that apply alternative forming processes to take advantage of the weight reduction opportunities of aluminum, magnesium, titanium, and high-strength steel in a cost-effective manner also will be validated through full-scale components.
- MMCs—Strategies for reducing the cost of reinforced MMC components will be pursued with the intent of (1) developing low-cost powder metallurgy techniques, (2) reducing the costs of reinforcing additives, (3) reducing costs of preforms, and (4) reducing costs of processes for introducing reinforcing particles into cast components.
- Nondestructive evaluation—Rapid, reliable, repeatable methods for inspecting metal and composite parts in the manufacturing plant will be developed. The methods must be robust enough and fast enough for a typical assembly plant but sensitive enough to detect critical flaws.
- Low-cost carbon fiber—Production methods will be developed for significantly reducing the cost of carbon fiber; they include microwave carbonization, radiation stabilization, plasma oxidation, and improvements in line speed and production downtime. Because of interface issues between different technologies and the relatively young age of the carbon fiber industry, it will be necessary to integrate the wide variety of new technologies into a single demonstration line and designate that line as a "DOE User Facility."

C. **Design methodologies.** To best take advantage of the properties of polymer composite and lightweight metals in automotive structural components, a significant shift must be made in component design philosophy. Additionally, the differences in properties of materials under consideration require the development of enabling technologies to predict the response of materials after long-term loading, under exposure to different environments, and in crash events. The following research is being pursued to address these problems:
   - Long-term effects—Research will be pursued to develop the understanding and predictive capability to assess the effects of low-energy impacts, creep, fatigue, automotive fluids, temperature extremes, and other influences to which materials will be subjected in an automotive environment. Predictive models will be developed that account for the synergistic effects of environmental factors. Models will be developed that can predict the deformation behavior and the performance of lightweight materials.
   - Design methods—Efforts will be pursued to develop design methodologies and material use philosophies that take advantage of the positive properties of composite materials, aluminum, advanced high-strength steels, magnesium, and titanium while minimizing the effects of their less desirable properties. These efforts will be pursued through joint DOE/industry tasks for developing test articles that represent automotive structures and subsystems.
   - Energy management testing and models—Theoretical and computational models will be developed and validated for predicting the energy absorption and dissipation in automotive composites and other lightweight materials. The combination of the models and the experimental data will give designers the tools to minimize component weight while maximizing occupant safety.

D. **Joining.** Nonferrous materials require significantly different joining methods than steel. Joining methods must be rapid, affordable, repeatable, and reliable and must provide at least the level of safety that currently exists in production automobiles. The following technologies are being pursued for joining nonferrous materials:
   - Aluminum, magnesium, and high-strength steel joining—Methodologies will be pursued for optimizing joining techniques for aluminum, magnesium, and high-strength steel using alternative technologies.
   - Composite joining—Research will be performed on alternative technologies for joining composites to composites, composites to steel, and composites to aluminum.
   - Nondestructive inspection—Thermal imaging, ultrasonic, and other methods for evaluating joint integrity will be developed that are able to qualify and quantify joint strength. These methods must be robust enough for a manufacturing facility, fast enough for a production line, and reliable enough to ensure passenger safety.

E. **Recycling and repair.** Methods for separating and recycling nonferrous materials will be pursued that look at the in-plant and post-consumer waste streams. This work will be conducted in conjunction with industrial consortia and other organizations as appropriate.

- Resin/fiber separation and reuse—Methods will be pursued for separating carbon fiber from thermoset and thermoplastic resin systems. Economically viable uses for recycled fiber and resins will be developed, and methodologies for further blending and compounding for reuse will be investigated.
- Post-shred residues—Technology for the cost-effective recovery of materials from post-shred residues will be developed and demonstrated.
- Light metals—Methods will be developed for sorting aluminum, magnesium, and other shredded automotive light-metal scrap. Purification of in-plant and post-consumer magnesium scrap will be addressed. Technologies to recycle MMCs into high-value products will be pursued.
- Repair of aluminum, magnesium and composites—Robust methods will be developed for rapidly and reliably repairing aluminum, magnesium, and composite structures. The cost-effectiveness of repair vs. replacement of components will be considered; the outcome will influence the joining technologies needed to incorporate alternate materials.

Research will focus on technologies for achieving the priority FCVT goals and FreedomCAR and Fuel Partnership goals. To achieve these measures and goals, a significant portion of the steel and iron must be replaced with aluminum or reinforced composites. Magnesium may replace many cast aluminum components and some ferrous components. In addition, advanced high-strength steels, MMCs, and titanium will be required for some applications that cannot be satisfied by polymer matrix composites, magnesium, or aluminum. It is anticipated that weight reduction research on components currently fabricated with copper, brass, zinc, rubber, and glass will be supported by industry, other agencies, and/or DOE efforts on an as-required basis.

Task Descriptions

Table 32 describes the tasks necessary for successful development of the various types of materials, including task descriptions, durations, and pertinent barriers. The schedule for and the relationships among the tasks are shown on the ALM network chart at the end of this sub-section. Milestones have been established and are shown in the network chart.

Table 32. Tasks for Automotive Lightweighting Materials

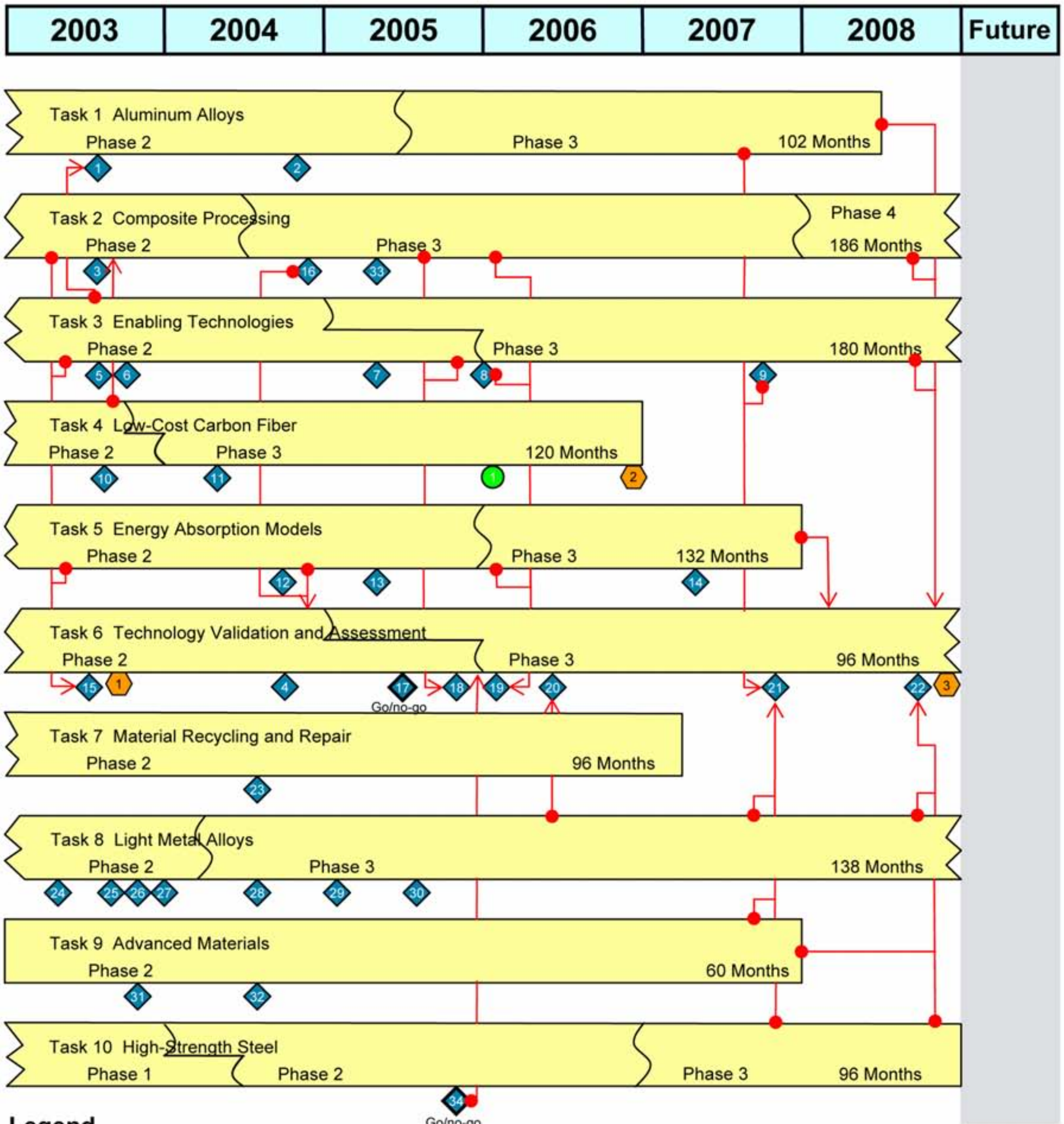
Task	Title	Duration/ barriers
1	Aluminum Alloys Phase 1 (Completed) • Developed continuous casting technologies and non–heat treatable aluminum alloy sheet, optimized cast-product design knowledge, developed cost-effective semi-solid forming technology, and developed technologies to extend life of dies for aluminum die-casting	36 months Barriers A, B
	Phase 2 • Evaluate and improve forming processes for aluminum automotive components • Complete development and optimization of electroforming technologies • Complete development of advanced forming technologies such as hydroforming, warm forming, and variable binder control for aluminum components	30 months Barrier B *(began 4Q 2002)*
	Phase 3 • Evaluate and develop alternative technologies for low-cost processing of sheet aluminum alloys, e.g. spray rolling, for automotive applications • Develop low-cost continuous casting technology for production of high-quality 6××× series aluminum sheet for application in outer panels	36 months Barriers A, B *(begin 3Q 2005)*
2	Composite Processing Phase 1 (Completed) • Developed rapid preforming and processing technologies for glass-reinforced composites	42 months Barrier B
	Phase 2 • Develop the processing capability to use rapid preforming technology for carbon fiber composites for automotive preforms that achieve automotive production rates and 1.5-mm thicknesses • Optimize discontinuous fiber composite processing technologies to achieve realistic production speeds, quality, and cost-effectiveness	42 months *(began 1Q 2001)*
	Phase 3 • Develop the processing capability to combine rapid preforming with thermoplastic resins to accomplish preforming and molding on one machine, followed by thermoforming • Demonstrate production-ready molding and forming technologies in a full-scale demonstration based on carbon fiber composites	42 months *(begin 3Q 2004)*
	Phase 4 • Develop the processing capability to combine rapid preforming technology for carbon fibers and glass to make hybrid material automotive preforms that achieve automotive production rates and 2.0-mm thickness • Begin processing studies using advanced polymer fibers as reinforcements	60 months *(begin 1Q 2008)*
3	Enabling Technologies Phase 1 (Completed) • Developed a design database, design methodology, joining methodologies, non-destructive evaluation techniques, and durability protocol for glass-fiber composites and joining processes for dissimilar materials and aluminum	72 months Barrier C

Table 32. Tasks for Automotive Lightweighting Materials		
	Phase 2 • Develop a design database and design methodology for thermoset carbon-fiber composites, including durability and processing parameters • Develop reliable joint test methodologies and novel joint design technologies for hybrid material joints • Evaluate reliable joining processes for dissimilar materials, including mechanical fastening, pulse bonding, friction stir welding, and other advanced joining techniques • Develop nondestructive evaluation processes for fiber-reinforced-composite and metallic components and installed parts, including predictive performance capability • Develop designer-usable joint models to aid structural engineers in designing joints for weight reduction and occupant safety optimization • Develop models for prediction of the response of metallic components to deformation during forming and during use • Develop predictive tools for polymer composite property retention • Demonstrate joining technologies for application to joining of different product forms, e.g., hydroformed tubes to castings • Develop on-line and near-real-time nondestructive evaluation methods for inspection of joining processes to determine bond quality and quantify defects • Develop nondestructive evaluation methods to measure and/or verify lay-up of fibers, resin fill, resin infiltration, fiber wetting, and curing for polymer composites	60 months Barrier C *(began 1Q 2001)*
	Phase 3 • Develop aluminum rivets for joining of aluminum components • Develop predictive models for dimensional control of welded assemblies • Develop a design database and design methodology for thermoplastic automotive fiber-reinforced composites, including durability and processing parameters. Glass fibers, carbon fibers, or other advanced reinforcements may be used • Integrate all joining-related tasks into demonstrations that highlight the benefits of all technologies developed earlier and demonstrate industry-acceptable assembly • Develop joining and assembly technologies to ensure adequate dimensional control	60 months Barrier C *(begin 1Q 2005*)
4	Low-Cost Carbon Fiber Phase 1 (Completed) • Demonstrated the technical and economic viability of using alternate, low-cost precursor materials and production processes for making carbon fiber	36 months Barriers A, B
	Phase 2 • Optimize a nonthermal process of carbonizing and graphitizing carbon fiber from polyacrylonitrile • Complete development of alternate precursors for producing low-cost carbon fiber and demonstrate feasibility of an advanced much lower-cost precursor • Develop non-thermal methods for stabilizing and oxidizing carbon-fiber precursors while demonstrating technical and economic feasibility	48 months Barriers A, B *(began 1Q 2000)*
	Phase 3 • Develop a carbon-fiber research user facility • Complete development of advanced stabilization and oxidation methods	36 months Barriers A, B

Table 32. Tasks for Automotive Lightweighting Materials		
	• Validate scaled-up processes through economic and technical analysis • Assist industry in implementing the new technologies	*(began 4Q 2003)*
5	Energy Absorption Models Phase 1(completed) • Developed and validated energy absorption material models for advanced structural materials and a composite-intensive vehicle	60 months Barrier C
	Phase 2 • Develop the capability to do high-rate testing and data acquisition for validation of models and development of novel design concepts • Evaluate the energy-absorption capability of a hybrid-material body-in-white • Develop understanding of the effect of strain-rate-dependent materials on crash energy absorption capabilities • Evaluate the energy absorption capabilities of bonded and mechanically fastened structures • Develop an energy management design database for magnesium alloys and structures • Develop test methods, constitutive materials models, and finite-element analysis guidelines for simulation of crash energy absorption of high-strength steels and magnesium	48 months Barrier C *(began 1Q 2002)*
	Phase 3 • Develop and validate energy-absorption subsystem models and integrate those models into a vehicle structure • Validate vehicle-level models in crash tests	24 months Barrier C *(begin 1Q 2006)*
6	Technology Validation and Assessment Phase 1 (Completed) • Verified that technologies developed yielded a 25% weight reduction of body and chassis at acceptable cost. Completed a demonstration based on glass fiber composites	
	Phase 2 • Through modeling and analysis, verify that technologies developed will yield >50% weight reduction of body and chassis • Develop tooling and demonstrate key component technologies enabling at least 50% weight reduction for body and chassis components • Complete a demonstration that integrates all of the carbon-fiber-based research tasks to demonstrate technical and economic viability	36 months Barriers A, B, C, D, E, 54 months *(began 1Q 2003)*
	Phase 3 • Develop tooling for all components, fabricate and assemble components, and demonstrate weight reduction and quality assurance processes required for high-volume production for thermoplastic composite structures • Complete a demonstration that integrates all of the thermoplastic composite and advanced reinforcement development research to demonstrate technical and economic viability of the technologies	60 months *(begin 1Q 2005)*
7	Material Recycling and Repair Phase 1 (Completed) • Evaluated processes for sorting aluminum alloys, recovering carbon fiber, and recycling magnesium scrap	36 months Barrier E
	Phase 2 • Extend aluminum scrap-sorting technologies to other light metals, such as magnesium and titanium	60 months Barrier E

Table 32. Tasks for Automotive Lightweighting Materials		
	• Develop recovery processes for separating the high-value fiber from the resin • Provide recycled fiber for process trials • Develop and demonstrate technologies for "post-shred" residue materials recovery • Pursue development of technology for removal of PCBs and other substances of concern from recycled automotive materials • Scale-up fiber-reinforced composites recovery and separation processes and implement them in a large-scale recycling system for full vehicle parts • Develop technologies for repair of structural/safety components • Develop technologies for recycle of metal matrix composites, high-strength steels, etc.	*(began 2Q 2002)*
8	Light Metal Alloys Phase 1 (Completed) • Developed improved alloying for creep-resistant magnesium alloys and performed exploratory research on processing technologies with a potential for low-cost ($5/lb) primary titanium	42 months Barrier A
	Phase 2 • Develop and optimize processing technologies for direct reduction of MgO to produce primary magnesium at reduced cost • Evaluate the economic feasibility of emerging processes for cost-effective production of titanium • Evaluate properties of test components produced from titanium powders made using low-cost processing techniques • Develop compositional variants of magnesium alloys to optimize properties • Optimize design knowledge and product capabilities for cast magnesium components with improved strength and ductility and validate with full-size components • Explore optimized secondary processing of cast aluminum metal matrix composites, develop lower-cost finishing technologies, and demonstrate on full-sized component • Develop coating technologies to improve corrosion and wear resistance of magnesium alloy components	36 months Barrier A *(began 2Q 2001)*
	Phase 3 • Perform R&D on processing technologies that have proved successful through the exploratory research phase and have a potential for low-cost ($5/lb) primary titanium • Develop low-cost manufacturing and machining processes for titanium components, including direct casting of titanium bar and rod products • Conduct validation tests on cast magnesium structural and powertrain components • Develop warm-forming technology for magnesium sheet • Investigate the potential for lost-foam casting of magnesium alloys for powertrain components	60 months Barrier A *(begin 2Q 2004)*
9	Advanced Materials Phase 1 (Completed) Phase 2 • Develop technologies for cost-effective fabrication and assembly of advanced metal components	 60 months Barrier B *(began 1Q 2003)*

Table 32. Tasks for Automotive Lightweighting Materials		
	• Develop technologies for lightweight, cost-effective alternatives to glass closure panels • Develop advanced polymer reinforcing fibers and micro-particle composite reinforcement technologies • Develop non-thermal methods for cross-linking thermoplastic resins with and without reinforcements • Develop the concept for hybrid material structure focal project and initiate tasks to develop necessary technologies • Develop and validate cost-effective technologies for fabrication of ultralight tailored structural materials, including metal foams, syntactic materials, and novel composites • Investigate properties of nanostructured materials made from machining chips and identify potential applications	Barrier A
10	High-Strength Steel Phase 1 • Develop forming technologies for advanced high-strength steels to enable 25% mass savings in front end structure • Conduct stamping trials and compare them with computer simulations • Develop durable die materials for hot metal gas forming of high-strength steels	36 months Barriers B, C *(began 3Q 2001)*
	Phase 2 • Develop an understanding of the formability of high-strength steel sheet during tubular hydroforming • Optimize forming and joining technologies for transformation-induced-plasticity (TRIP) steels • Improve accuracy and confidence in finite element modeling of high-strength steel forming • Develop an understanding of steel-lubricant interactions during forming	36 months Barriers B, C *(begin 1Q 2004)*
	Phase 3 • Extend investigations of the forming technologies for advanced high-strength steels for front-end structures to the passenger compartment and rear-end structure	24 months Barriers B, C *(begin 1Q 2007)*



Legend

Milestone

1. Establish formability criteria for finite element modeling of aluminum, using stress-based or damage models of failure
2. Complete development of binder control system for stamping of aluminum sheet components
3. Complete processing study of the molding of P4 carbon preforms by the injection/compression process using the Automotive Composites Consortium B-pillar shaped mold
4. Validate carbon-fiber rapid preforming technology
5. Publish report, *Durability-Based Design Criteria for Chopped-Carbon-Fiber Composite*
6. Determine joint performance of dissimilar aluminum alloys and steels (dual-phase and HSLA350) with and without adhesive
7. Complete development of predictive models for dimensional control of welded assemblies
8. Demonstrate welding technologies for application to joining of different product forms of aluminum (e.g., hydroformed tubes to castings)
9. Demonstrate dimensional control for welded aluminum
10. Complete development of the required underlying technology (hardware, process conditions) and the demonstration of a continuous 24 inch/minute production line speed, multiple-tow, microwave-assisted plasma carbonization processing unit
11. Demonstrate technical and economic ability to use lignin as the base for precursors for low-cost carbon fiber
12. Develop an understanding of the effect of strain-rate-dependent materials on crash energy absorption capabilities
13. Complete evaluation of energy-absorption capabilities of prototype bonded and mechanically fastened structures

Milestone

14. Validate vehicle-level models for energy absorption in crash tests
15. Complete detailed design of entire composite-intensive body-in-white, along with cost, weight, and performance analysis
16. Complete part fabrication for composite-intensive body-in-white
17. **Go/no-go**: Complete cost, weight, and performance analysis of composite-intensive body-in-white
18. Complete composite-intensive body-in-white testing and verification
19. Complete design for hybrid materials focal-project structure
20. Complete vehicle testing of magnesium powertrain components
21. Complete hybrid-material body-in-white assembly
22. Complete first prototype of hybrid materials focal-project structure and identify manufacturing process
23. Complete evaluations of technologies for bulk separation of shredder residue, including electrostatic separation, hydrodynamic floatation, and gravity table separation
24. Complete castability trials of selected Mg alloys to ensure that alloys with best high-temperature properties are castable into powertrain components
25. Complete casting trials of highly reinforced aluminum metal matrix composite prototype brake rotor, having 40 volume percent reinforcement
26. Demonstrate technologies for producing low-cost cast aluminum metal matrix composites in full-size components
27. Review cost analysis of cast Mg engine cradle to verify that the process achieves the best quality, performance, and economic value

Milestone

28. Complete development of creep-resistant magnesium alloys and initiate validation tests of automotive component
29. Develop corrosion/wear coatings for completed magnesium components
30. Optimize design knowledge and product capabilities for cast magnesium structural components and validate with full-size component tests
31. Complete the noise prediction models and issue a technical report describing the model and side-door glass optimization studies
32. Demonstrate 50% mechanical property improvement over unreinforced resins using micro-composite technology
33. Demonstrate proof-of-principle feasibility to crosslink commercial resin systems using non-thermal energy methods
34. **Go/no-go**: Demonstrate and validate 25% mass savings in front-end structure made of advanced high-strength steels

Technology Program Output

1. Composite intensive body-in-white weight and performance analysis available to Vehicle Systems Analysis
2. Validated technologies for production of Carbon Fiber at a cost of \$3/lb available to industry
3. Hybrid body-in-white weight and performance data available to Vehicle Systems Analysis

Supporting Input

1. Validated carbon fiber oxidation technologies provided from the High Strength Weight Reduction Materials technology area

4.6.2 Automotive Propulsion Materials

The vision of the APM activity is to improve operating efficiency and reduce the costs of engine systems and power electronics. The APM is an integral partner with and provides enabling technologies for the Advanced Power Electronics and Advanced Combustion Engine sub-programs. Research performed under this activity is primarily focused on light vehicle applications; however, it is recognized that the technologies may also have application on heavy vehicles. Management of this activity and the Heavy Vehicle Propulsion Materials activity are coordinated to ensure that they are complementary, rather than duplicative.

Goals

The technical goals of the APM activity are the goals of the Advanced Power Electronics and Advanced Combustion Engine sub-programs and are not repeated here. The goals for Advanced Power Electronics and Advanced Combustion Engines are listed in Sections 4.4 and 4.5, respectively, of this report. In addition, APM-specific goals are these:

- By 2007, validate carbon foam durability and effectiveness in power electronic cooling applications.
- By 2005, complete the testing and validation of a diesel particulate filter with 95% effectiveness for the life of the vehicle.

Programmatic Status

A microwave-regenerated exhaust filter system has been developed. This pleated filter system has about 1/20th of the backpressure of conventional filters, captures more than 95% of the diesel particulates, and is cleaned using an onboard microwave. Significant progress has been made in the development of smaller, lighter-weight, high-temperature electronics and advanced cooling systems.

Targets

The APM activity supports the achievement of the goals and objectives of two core FreedomCAR and Fuel Partnership research areas as indicated in Table 33.

Table 33. Technical targets: Automotive Propulsion Materials

Automotive Propulsion Materials	Technical targets
Thermal management materials	Durability and effectiveness for 15 years
Diesel particulate filter materials	Greater than 95% removal for the life of the vehicle

Barriers

The barriers for APM are shown as system barriers in Table 34. The associated enabling materials barriers are shown and are keyed to the system barriers.

Table 34. Automotive Propulsion Materials barriers		
System barriers		**Materials barriers**
Current NO_X and PM emissions from advanced combustion engines exceed the targets by a factor of four to eight	A.	Materials and technologies used to reduce NO_X and PM emissions are ineffective and unreliable
Thermal management	B.	Heat transfer of materials used in heat exchangers and heat sinks is too low
Cost of electric drive systems and advanced combustion engines	C.	Materials and manufacturing methods for electric drive systems and advanced combustion engines are too costly

Approach

To achieve the activity goals and overcome the technical barriers, the APM activity has initiated enabling research that addresses the materials barriers identified.

Emissions reduction. Current technologies used to reduce NO_x and PM emissions from diesel engines create significant backpressures and are ineffective, unreliable, and very costly. New technologies such as microwave-regenerated particulate traps, non-thermal plasma systems, and improved NO_x catalysts are being developed to reduce NO_x and PM emissions.

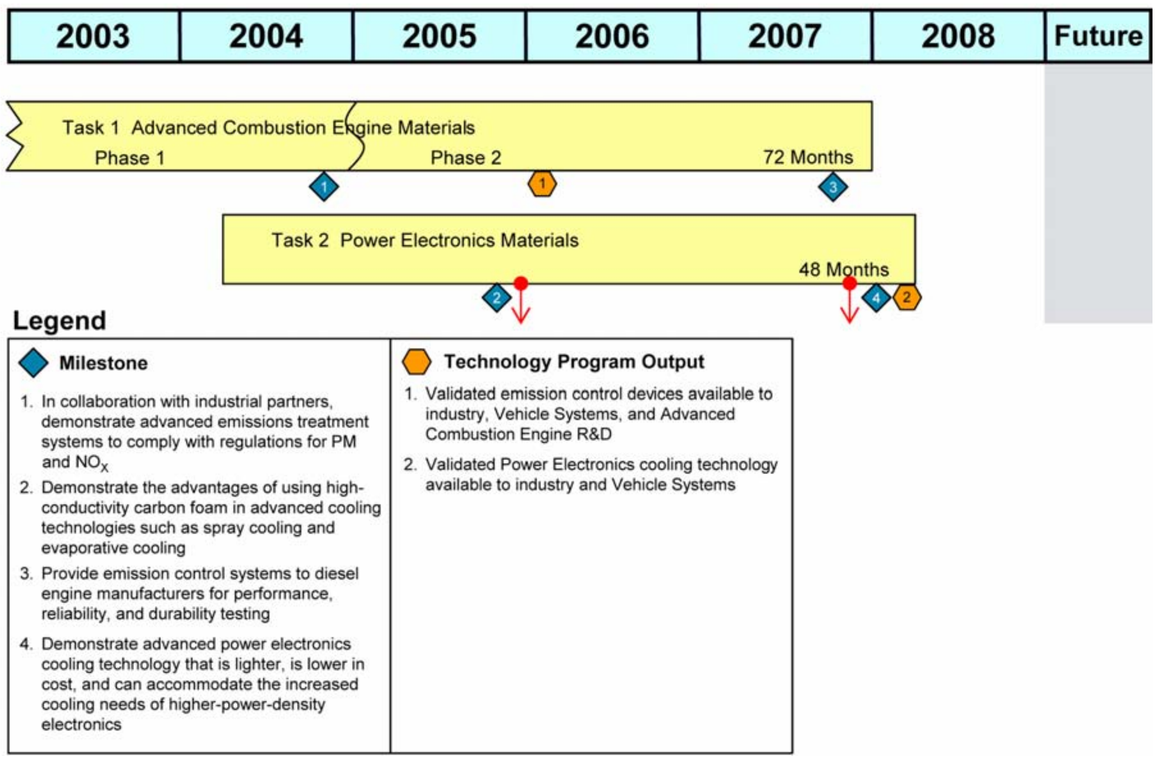
Thermal management materials. Faster computer chips and higher-power components are being developed that will generate more heat and be more difficult to cool than today's electronics. Advanced cooling technologies that use spray or evaporative cooling and/or high-conductivity carbon foam are being developed.

Cost. The materials and manufacturing methods used to fabricate small, lightweight, electric-drive systems and advanced combustion engines are very costly. Processes are being developed to fabricate smaller, lighter, and less-costly electronics and engines.

Task Descriptions

Table 35 describes the tasks necessary for successful development of the materials and technology to address the pertinent technical barriers of this activity. The task descriptions and duration of the tasks are shown in Table 35.

Task	Title	Duration/ barriers
1	Advanced Combustion Engine Materials Materials research on aftertreatment devices Phase 1 • Fabricate prototype microwave-regenerated particulate filter system for vehicle testing • Develop a fast, highly selective NO_X sensor	36 months Barriers A,E
	Manufacturability/durability research Phase 2 • Develop low-cost processing techniques to fabricate metallized ceramic dielectric components for non-thermal plasma reactors	36 months Barriers A,E
2	Power Electronics Materials • Optimize the structure and properties of carbon foam for improved heat transfer and durability • Design, test, and evaluate advanced designs for lighter and more efficient heat exchangers and heat sinks	48 months Barriers B,E



4.6.3 High Strength Weight Reduction Materials

The vision of the HSWR Materials activity is to reduce parasitic energy losses due to the weight of heavy vehicles. In addition, it is recognized that improved materials may enable implementation of other technologies that can further improve the fuel efficiency of the vehicles. The research will achieve this vision by identifying lightweighting materials and materials processing technologies that can contribute cost-effectively to reducing the weight of the vehicle without sacrificing functionality, durability, reliability, or safety. Research performed under this activity is primarily focused on heavy vehicle applications; however, it is recognized that the technologies may also have application on light vehicles. Management of this activity and the ALM activity are coordinated to ensure that they are complementary, rather than duplicative.

Goals

The goals of this activity include the priority FCVT goal identified in Section 3 for the reduction of tractor-trailer combination weight. In addition, the goals directly support the 21st CTP goal for weight reduction of vehicle structures and subsystems.

- By 2010, reduce the weight of an unloaded tractor-trailer combination from the current 23,000 lb (2003) to 18,000 lb, a reduction of 22%.
- Enable significant reductions in the weight of heavy vehicles. (For example, the 21st CTP goal is a 15–20% reduction in weight of Class 8 tractor-trailer combinations relative to 2002 vehicles. Goals for other classes of heavy vehicles vary between 10 and 33% reductions in vehicle weight, depending on performance requirements and duty cycles.)

These goals will be met with the constraint that the materials

- Exhibit performance, durability, reliability, and safety characteristics comparable to those of conventional vehicle materials
- Be cost-competitive, on a life-cycle basis, with costs of current materials
- Be consistent with the materials regulation requirements of our socially and environmentally responsible national industries

Programmatic Status

To achieve the priority FCVT goal to reduce vehicle weight by 22% by 2010, HSWR Materials has been developing a broad spectrum of advanced materials technologies that can be applied to a wide array of body, chassis, and suspension vehicle components. The research required to develop these technologies is too high-risk to be pursued independently by the heavy vehicle industry because of substantial uncertainties regarding return on investment.

Although a number of tasks have been initiated to address weight reduction targets, significant barriers still exist that prevent timely application of these materials to heavy vehicles. The R&D tasks of HSWR Materials are being conducted through a variety of contractual mechanisms. Research partners include heavy vehicle manufacturers, first-tier and materials suppliers, national laboratories, and other non-profit technology organizations. By virtue of a natural overlap of interests in materials, the interactions of the HSWR Materials activity are primarily the same as those identified for the ALM activity. However, frequent and detailed communication ensures effective collaboration and technology development that benefits both activities. Yet they differ inasmuch as the performance requirements for heavy vehicle components are typically several times larger than those for passenger and light-duty vehicles.

Targets

The technical targets to be achieved by the HSWR Materials activity are listed in Table 36.

Table 36. Technical targets: High Strength/Weight Reduction Materials (Class 8 over-the-road tractor)

Characteristics	Calendar year				
	2003	2006	2009	2012	2015
Weight of cab, closures, and interior[a] (Note: Cab weight reduction is larger than 20% to make up for lower weight reductions in powertrain and exhaust aftertreatment)	3230	2940	2560	2310	1970
Aluminum cab life cycle cost relative to steel	2×	1.5×	1×	1×	1×
Hybrid glass/carbon-fiber-reinforced composites life-cycle cost relative to steel	3×	2.5×	2×	1.5×	1×
Hybrid metal/fiber-reinforced composite life-cycle cost relative to steel	3×	2×	1.5×	1×	1×
Carbon-fiber-reinforced composite life-cycle cost relative to steel	4×	3×	2×	1.5×	1.5×
Weight of chassis in pounds[b]	3570	3330	3090	2850	2610
Aluminum/magnesium chassis life-cycle cost relative to steel	1.5×	1.5×	1.2×	1×	1×
Carbon and/or carbon-/glass-fiber-reinforced chassis life-cycle cost relative to steel	3×	2.5×	2×	1.5×	1.5×
Weight of drivetrain subsystem in pounds[c]	4590	4300	4000	3670	3370
Aluminum/magnesium intensive drivetrain subsystem life-cycle cost relative to steel	2×	1.5×	1×	1×	1×
Carbon and/or carbon-/glass-fiber-reinforced composite-intensive drivetrain life-cycle cost relative to steel	4×	3×	2×	1.5×	1.5×
Weight of powertrain system in pounds[d] (Note: Powertrain not expected to reach 20% weight reduction due to increased weight of aftertreatment)	5610	5330	5050	4770	4490
Total vehicle weight in pounds	17000	15900	14700	13600	12440

[a] Includes cab in white, sleeper unit, hood and fairings, interior and glass.

[b] Includes frame rails, cross-members, brackets, fifth wheel, fuel systems, and fasteners.

[c] Includes drive axles, steer axles, suspension system, and set of ten wheels and tires.

[d] Includes engine and cooling, exhaust and exhaust aftertreatment systems, transmission, engine accessories, and batteries. The HSWR Materials program does not directly address engine weight reduction efforts.

Barriers

A. **Cost.** Prohibitively high cost is the greatest single barrier to the viability of advanced lightweighting materials for heavy vehicle applications.
B. **Design and simulation technologies.** Adequate design data for heavy vehicle structures (e.g., materials property databases for properties of interest for heavy vehicles, such as durability, corrosion, and fatigue), test methodologies, analytical simulation tools, and durability data do not exist for many lightweight materials.
C. **Manufacturability.** Methods for the cost-competitive production of components for heavy vehicles in volumes of interest to the heavy vehicle industry are not sufficiently well developed.
D. **Tooling and prototyping.** The cost of tooling for forming components made with lightweight materials is too high for the volumes typical for the heavy vehicle industry. The development and fabrication time required for prototyping components is too high.
E. **Joining and assembly.** High-yield, robust joining technologies for lightweight materials are not sufficiently developed.
F. **Maintenance, repair, and recycling.** Technologies for cost-effective maintenance and repair are inadequate for many lightweight materials.

Approach

To achieve the HSWR goals, it is imperative that lighter-weight materials be developed to replace conventional materials (i.e., mild steel) for body, chassis, and suspension applications while still meeting the demanding performance requirements of heavy vehicles (e.g., strength, stiffness, durability, reliability). These imperatives will be addressed by developing materials and processing technologies, validating these materials through component prototyping, and developing adequate design data and design methodologies to facilitate their beneficial application.

Relevant materials include light metals; advanced engineered materials, such as MMCs and ultralight materials (e.g., engineered laminate materials and foams); materials that enable lightweighting, such as advanced high-strength steels or stainless steels; and reinforced polymer composites. These materials must be strategically applied to optimally match their special properties to key application needs. This approach will allow reduced weight at minimal or no cost penalty while still addressing the optimization of strength and stiffness; improvement of vehicle dynamics, handling, and safety; and improvement of durability and maintenance. It will also be necessary to develop robust, flexible, and reliable manufacturing processes to optimize for part consolidation, net shape forming, lower assembly costs, and low-cost tooling. Finally, the total life cycle costs to the trucking industry demand that maintenance, repair, and recyclability be addressed. Within the timeframe of this plan, materials research will be balanced between nearer-term objectives and longer-term, higher-risk materials research. Research tasks have been identified to address the most significant barriers within the technical activities that the materials community considers higher-risk but that, if successfully developed, would result in significant progress toward the activity goals. The technology development tasks have been identified through workshops, white papers, and planning assessments and have led to supported efforts on composites, steel, aluminum, magnesium, and titanium. Six areas of research have been identified.

A. **Cost reduction.** The number-one need for all lightweight materials is lower cost for primary materials. However, in many cases, such as the extraction of metals from ore, the technology development need is beyond the scope of the HSWR Materials activity. In some cases, it is being addressed elsewhere. Nonetheless, the feasibility of novel technologies with potential to address this basic need will be explored when appropriate. The life cycle costs of lightweight materials will also be addressed by (1) developing technologies that enable parts consolidation and reduce the cost of secondary processing during manufacturing and (2) materials developments that enhance the durability of these materials so that replacement intervals can be extended.

B. **Design and simulation technologies.** User-friendly databases will be developed that are easier to use for both design and simulation. They must reflect accurately the performance needs of heavy vehicles, including durability, corrosion, and fatigue. Materials-specific design methodologies will be developed, for both advanced metals and composites, that take advantage of the inherent characteristics of the various materials and allow designs to be optimized for weight, manufacturability, performance, safety, and cost. Development of both system-level and component-level design and manufacturing modeling tools will be pursued to enable industry to realize the advantages provided by lightweight materials, either alone or in combination. Accelerated test methods that simulate materials behavior under operating conditions must also be developed. Theoretical and computational models will be developed and validated to optimize the microstructure of materials for heavy vehicle applications with respect to mechanical and environmental performance. Finally, simulation tools will be developed that can predict the behavior of materials during the manufacturing process, as well as the response of materials after long-term loading, under exposure to different environments, and in crash events.

C. **Manufacturability.** Processing technologies will be pursued that yield the required component shape and properties in a cost-effective, rapid, repeatable, and environmentally conscious manner. It is important that these technologies maximize component function and reduce part count, assembly cost, and weight. Technologies must be developed to enhance the capability to produce a class A finish for polymer composites. Alternative processes that take advantage of the weight reduction opportunities cost-effectively will also be pursued.

D. **Tooling and assembly.** Because the number of vehicles produced annually by the heavy vehicle industry is low compared with the number produced by the automotive industry, the cost of tooling is more significant. The development of lower-cost, flexible tooling approaches will be pursued for shape forming of all materials, e.g., casting of magnesium, aluminum, and titanium; stamping of aluminum, magnesium, and advanced high-strength steels; and processing of composites. Faster tooling development processes that shorten lead-time and reduce prototyping steps will be developed.

E. **Joining and assembly.** Lightweight materials require different joining methods than plain carbon steel. New joining methods must be rapid, affordable, repeatable, and reliable and must provide at least the level of durability and safety that currently exists in production vehicles. In addition, joint designs for lightweight materials, either individually or in combination, must be developed to accommodate the higher performance requirements of heavy vehicles. Methods will be developed for evaluating joint integrity and strength. These methods must be robust and fast enough for a manufacturing facility while being durable and reliable enough to ensure vehicle safety.

F. **Maintenance, repair, and recycling.** Market dynamics and incentives must be understood as the major drivers for maintenance, repair, and recycle decisions. Maintenance and repair issues for cab structures are primarily associated with durability, i.e., fatigue-related failure and corrosion. The combination of dissimilar materials systems and extended exposure to wet, corrosive, and abrasive road conditions present significant challenges. Research will be focused on developing low-cost corrosion-resistant materials and coatings. Improved methods for detecting and monitoring corrosion to replace visual inspection will also be developed to allow for timely preventive maintenance. Major damage modes for trailers are structural damage from impacts (driver-related), structural damage due to forklift impacts, and corrosion. Low-cost, robust, field-deployable repair procedures must be developed for lightweight materials and hybrid materials systems. Techniques for cost-effective disassembly will be investigated.

Task Descriptions

Table 37 describes the tasks necessary for successful development of the various types of materials, including task descriptions, durations, and the pertinent barriers. The schedule for and the relationships among the tasks are shown on the network chart at the end of this sub-section. Milestones have been established and are also shown on the network chart.

Table 37. Tasks for High Strength Weight Reduction Materials

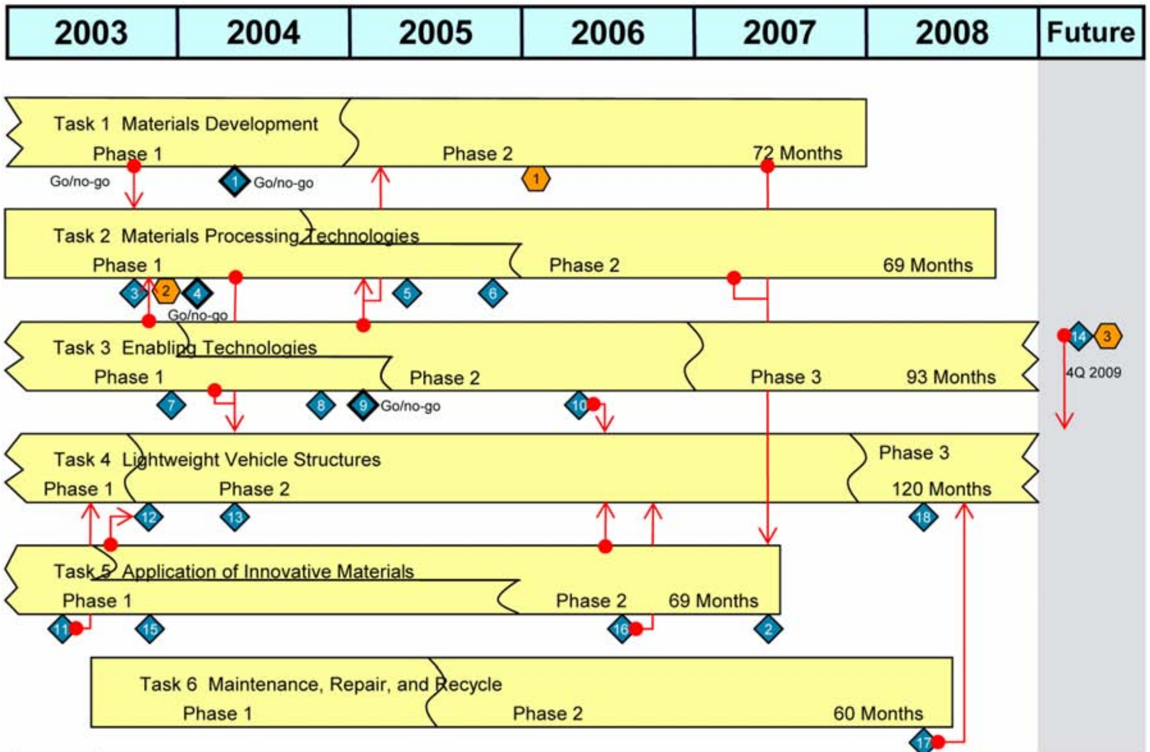
Task	Title	Duration/ barriers
1	Materials Development Phase 1 • Develop wrought magnesium alloys for high-strength, reduced-weight truck components • Develop carbon-fiber sheet molding compound materials that meet heavy vehicle manufacturers' needs for properties, manufacturability, and surface finish • Evaluate the application of high-strength stainless steels for lightweighting applications in heavy vehicles to improve corrosion resistance and durability • Develop cast magnesium alloys with improved properties for structural applications	36 months Barrier A,C *(Began 1Q 2002)*
	Phase 2 • Develop low-cost corrosion-resistant materials and coatings • Develop polymer materials or protective treatments to improve UV resistance and tolerance for weather and impact damage • Develop advanced, low-cost cermets and carbon-carbon brake friction materials that provide reduce weight and improved safety	36 months Barrier A, C,F *(begin 1Q 2005)*

Table 37. Tasks for High Strength Weight Reduction Materials

	• Develop low-cost magnesium metal matrix composites for heavy vehicle applications	
2	Materials Processing Technologies Phase 1 • Develop advanced casting processes for the production of high-integrity aluminum, magnesium, and metal matrix composites for heavy vehicle applications • Develop technologies for reducing the cost of carbon fiber by significantly reducing processing time • Evaluate and improve forming processes for aluminum components • Develop innovative processing technologies that result in improvements in the formability of wrought magnesium	36 months Barrier A,C *(began 1Q 2003)*
	Phase 2 • Develop surface treatment technologies as cost-effective techniques for reducing friction and wear • Develop lower-cost processing and manufacturing processes for titanium • Complete development of advanced stabilization and oxidation methods for carbon fiber composites and integrate them into the processing line. (This research is complementary to Task 4 of the ALM activity) • Scale-up processing technologies for production of formable magnesium alloy sheet and validate performance on prototype components • Develop new, innovative manufacturing and assembly techniques for carbon fiber composites and hybrid material structures, including the capability to produce class A surfaces • Develop improved casting technologies for light metals and high-strength steels that result in thinner, lighter castings with improved fatigue and corrosion resistance • Develop casting technologies that provide flexibility in controlling and varying wall thicknesses of large drivetrain and suspension castings	48 months Barrier B *(begin 3Q 2004)*
3	Enabling Technologies Phase 1 • Extend the capability of the friction stir process for joining high-strength materials • Evaluate reliable joining processes for dissimilar materials	36 months Barrier E *(began 2Q 2002)*
	Phase 2 • Develop design and modeling tools that optimize the microstructure, manufacturability, and performance of materials for heavy vehicle applications with respect to mechanical and environmental performance • Assess technologies for manufacturing tooling for lightweight materials, evaluate state-of-the-art capabilities for rapid low-cost tooling, and develop a technology roadmap for the development of high-impact, rapid, low-cost tooling • Evaluate or develop ultrasonic joining techniques for application to lightweight materials for advanced transportation systems • Develop attachment techniques for heavy truck composite chassis members • Develop designer-usable joint models to aid structural engineers in designing joints for weight reduction, durability, and occupant safety optimization • Develop design data and methodologies for hybrid material structures that take advantage of inherent characteristics of the materials and allow	36 months Barriers B,D,E *(begin 1Q 2004)*

Table 37. Tasks for High Strength Weight Reduction Materials		
	optimization for weight, performance, and cost • Develop accelerated testing methods to simulate materials and structural performance in operating environments that are acceptable to truck OEMs	
	Phase 3 • Integrate all joining-related tasks into demonstration efforts that highlight the benefits of all earlier developed technologies and demonstrate industry-acceptable assembly	36 months Barrier C,E *(begin 1Q 2007)*
4	Lightweight Vehicle Structures Phase 1 • Develop a high-performance, lightweight stainless steel transit bus structure weighing 50% less than a conventional transit bus • Develop a design and the manufacturing technology for a lightweight frame for a pickup truck/SUV that is 30% lighter at 1.25 times the cost of a standard vehicle • Develop selective reinforcement technology for hybrid materials that can be applied to large truck cab structures to improve strength and reduce weight by 40% • Develop the use of hybrid materials/composites as production Class 8 truck components that reduce weight by 40%	36 months Barrier C,E *(began 4Q 2000)*
	Phase 2 • Begin to competitively bid cost-shared efforts with truck OEMs to develop technologies for reduction in weight of Class 7 and 8 tractor-trailers	48 months Barriers A,B,C *(began 4Q 2003)*
	Phase 3 • Complete design for hybrid materials focal project for Class 8 vehicles • Complete prototype of hybrid materials focal project structure and identify manufacturing processes	36 months Barriers B,C,E (*begin 4Q 2007*)
5	Application of Innovative Materials Phase 1 • Develop a cost-effective carbon fiber sheet molding compound hood system conforming to the manufacturer's quality standards and reducing system mass by at least 35% for a Class 8 tractor • Develop long-fiber-reinforced polymer structural chassis components for Class 8 trucks so that the mass is 60% less than that of the incumbent design • Develop a carbon-fiber-reinforced polymer structural door surround for a Class 8 tractor cab that is 50% lighter	48 months Barrier C *(began 1Q 2002)*
	Phase 2 • Develop long-fiber-reinforced polymer chassis support structures (lateral cross-members and frame rails) for Class 7 and 8 trucks so that the component mass is 50% lighter • Develop test methods, constitutive materials models, and finite element analysis guidelines for simulation of crash energy absorption for lightweight components and structures • Develop processing technologies for low-cost magnesium metal matrix composite materials	48 months Barrier C *(began 3Q 2003)*

Table 37. Tasks for High Strength Weight Reduction Materials		
6	Maintenance, Repair, and Recycle Phase 1 • Evaluate the effect of ice-clearing chemicals on the corrosion of heavy vehicle materials and components, especially brake materials, and develop procedures for controlling the corrosion	24 months Barrier E *(began 3Q 2003)*
	Phase 2 • Develop improved, inexpensive, field-deployable systems that allow early detection of component degradation (due to corrosion or fatigue) to allow preventive maintenance • Develop technologies for repair of structural/safety components made of lightweight materials • Develop cost-effective disassembly procedures for maintenance, repair, and recycle • Develop technologies for recycle of metal matrix composites and light metals such as magnesium and titanium	36 months Barrier E *(begin 3Q 2005)*



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Milestone

1. **Go/no-go:** Demonstrate technical ability to oxidize carbon fiber precursors using non-conventional methods
2. Complete fabrication of low-cost magnesium metal matrix composite component and initiate vehicle testing
3. Complete testing of Mg alloy sheet produced using plasma arc lamp and pinch roller treatment and validate properties
4. **Go/no-go**: Complete the report detailing design of lightweight, one-piece cast frontwall for a Class 8 truck and present results to Freightliner and DOE program managers
5. Scale-up processing technologies for production of formable Mg alloy sheet and validate performance on prototype components
6. Demonstrate continuous production of aluminum connecting rod with improved mechanical properties using advanced casting process
7. Validate friction stir processing process models using instrumented process samples and mechanical property test results
8. Demonstrate cost-effective, rapid friction stir process for joining high-strength materials
9. **Go/no-go:** Demonstrate ability of microstructural level simulation model to predict the response of a 1500 series steel during machining of heavy-vehicle component
10. Demonstrate newly developed attachment techniques for carbon fiber composite heavy truck cross-members on full-size frame
11. Select cab structural component design and perform baseline finite element and modal analysis
12. Review proposals for "Development of Technologies for Reduction in Weight of Class 7 and 8 Tractor Trailers," announce awards, and initiate work
13. Complete development of prototype lightweight stainless steel bus structure weighing 50% less than conventional steel bus
14. Complete demonstration project integrating newly developed joining technologies and demonstrate industry-accepted assembly of subsystem
15. Complete advanced characterization studies of advanced carbon gas storage materials and publish paper
16. Complete validation testing of carbon-fiber-reinforced polymer structural door surround for Class 8 tractor cab that is 50% lighter
17. Complete development of field-deployable system for early detection of component degradation to allow for preventive maintenance and begin vehicle testing
18. Complete design for hybrid materials focal project for Class 8 vehicles

Technology Program Output

1. Validated carbon fiber oxidation technologies provided to the Automotive Lightweighting Materials technology area
2. Report detailing design of lightweight, one-piece cast firewall for a Class 8 truck available to industry subject to nondisclosure agreement
3. Composite of dissimilar joining technologies available to industry

4.6.4 Heavy Vehicle Propulsion Materials

The vision of the HVPM activity is to identify and provide improved and new materials to enable cost-effective, high energy-efficiency, heavy-duty engines with high durability and reliability and substantially lower emissions. Lightweight materials applications in heavy-duty engines may also provide an opportunity to reduce weight-induced parasitic energy losses, provided that the same cost, durability, and reliability requirements can be met. Research performed under this activity is primarily focused on heavy vehicle applications; however, it is recognized that the technologies may also have application on light vehicles. Management of this activity and the APM activity are coordinated to ensure that they are complementary, rather than duplicative.

Goals

The technical goals of HVPM, listed as follows, are in direct support of the Advanced Combustion Engine Sub-program, described in Section 4.5.

- By 2005, develop and validate advanced materials technology that will substantially reduce the erosion and corrosion in heavy-duty engines as a result of the use of EGR.
- By 2006, complete the development of materials solutions that will enable heavy-duty diesel engines to achieve efficiencies of over 50% while meeting EPA 2007 emissions standards.
- By 2008, develop applications in advanced diesel engines for titanium materials (metal or intermetallic alloys or composites) to substantially increase fuel efficiency and durability by virtue of the unique properties of titanium.
- By 2010, develop and validate a new class of materials based on advanced surface modifications or treatments and other compositional/microstructural modifications to increase the reliability and durability of diesel engine components.

Programmatic Status

Durable, cost-effective materials are being developed to enable the designing and manufacturing of advanced diesel engines, consistent with the goals of the FCVT Program and the 21st CTP, in general, and the overall priority FCVT goals, in particular. The HVPM activity has been developing materials and materials-processing technologies, validating these technologies through representative component prototyping, and developing adequate design data and design methodologies to facilitate their beneficial application.

Targets

The advanced engine system designs needed to meet the 21st CTP goals push the requirements for materials outside the envelope of the existing materials now used in engines. The technical targets for the HVPM activity are for materials technologies that will enable the 21st CTP goals to be met with respect to engine systems (referring to the combination of fuel, engine, and emissions aftertreatment equipment). Specific materials technologies that must be developed are identified in concert with the U.S. heavy-duty diesel engine community. These include material compositions and properties, as well as manufacturing technology, component cost, life prediction, and durability. Work is undertaken in collaboration with the engine manufacturers, component suppliers, and materials suppliers to develop practical, low-cost, and durable materials systems. The technical targets are shown in Table 38.

Table 38. Heavy Vehicle Propulsion Materials targets

Heavy Vehicle Propulsion Materials	Heavy Vehicle Engine technical targets
Fuel system materials	Efficiency > 50% (2010) >55% (beyond 2012)
Materials for air-handling, hot-section, engine structures	Engine life > 1 million miles
Exhaust aftertreatment materials	Compatible with future fuels

Barriers

The principal barriers to meeting the HVPM goals are in the areas of performance, manufacturability, and cost.

A. **Performance.** The technologies currently under consideration for reducing emissions result in significant fuel-efficiency penalties. In addition, many of these technologies may decrease the reliability and durability of the engine, for example, by increasing pressures and temperatures within the engine and introducing corrosive and erosive species into the engine. Materials needed to achieve the performance objectives in specific engine components may not exist today as durable, reliable materials.

B. **Manufacturability.** Advanced materials, by virtue of their unique physical and mechanical properties, are often difficult to manufacture with current technology. Other issues include joining of dissimilar materials, inspection, standards, availability of cost-effective and high-quality precursors and powders, and durability and cost of tooling.

C. **Cost.** Key advanced materials required to meet the efficiency and emissions goals for heavy vehicles are not available today in high volumes and do not have the required precision, reproducible quality, or acceptable cost.

Approach

The following materials research efforts are critical to meeting the HVPM activity goals.

Fuel system materials. The fuel system and air-handling system contribute significantly to the cost of a heavy-duty diesel engine. Enabling materials and cost-effective, precision manufacturing processes will be instrumental in developing improved fuel injection systems. The electronic fuel injectors on heavy-duty diesel engines operate at ~20,000 psi to minimize particulate emissions. The fuel injection pressure is likely to increase to as much as 35,000 psi to meet emerging emissions regulations while maintaining engine performance. The high-pressure fuel injection results in challenges with wear and scuffing of fuel injector plungers and with erosion, wear, and fatigue of fuel injector nozzles. In addition, low-sulfur fuels required to meet the low emissions targets typically do not lubricate the fuel injector components as well as current diesel fuel; therefore, wear- and scuff-resistant materials are necessary. Improved high-precision manufacturing and inspection methods for the injector components also are needed.

Exhaust aftertreatment materials. The sulfur in diesel fuel is a major barrier to several promising aftertreatment technologies. Currently available U.S. diesel fuel contains up to 500 ppm of sulfur. The sulfur content of highway diesel fuel will be reduced to less than 15 ppm. Even when fuel containing less than 15 ppm sulfur becomes available starting in 2006 (in conjunction with the EPA 2007 heavy-duty diesel engine emissions standards), catalyst poisoning will continue to be an issue for the durability of exhaust aftertreatment devices. Development of sulfur-tolerant catalysts and sulfur removal technologies (SO_x absorbers) is considered critically important to meeting future emissions regulations.

Catalyst materials with stable microstructures are needed that can operate at high efficiency over a wide range of exhaust conditions, including low temperatures and varying levels of oxygen and unburned fuel. R&D tasks are expected to include synthesis and processing studies, bench test and engine exposures, and postmortem analysis of the chemistry and microstructure of the catalyst systems.

Durability of exhaust aftertreatment systems in heavy vehicles is a major concern. Lifetimes of at least 500,000 miles are expected, and lifetimes of 1,000,000 miles are desired. Characterization of the effects of exposure in service on the microstructure and microchemistry of the aftertreatment systems will be needed. The characterization may lead to the development of more-durable systems and may point to material development paths that result in an optimized temperature window for aftertreatment operation.

Additional engine controls may be required that will depend on new sensors developed for reliable, real-time measurement of NO_x, O_2, temperature, and possibly some unregulated emission species over a wide range of temperatures and operating conditions. The sensor materials currently available are limited in range or require long lag times to respond to a change and thus are inadequate for measuring transient or rapid changes in operating conditions.

Materials for air-handling, hot-section, and structural components. Turbocharging and associated air-handling equipment are important elements of engine control for heavy-duty diesel engines, and advanced engines will place new demands on the air-handling system. Cost-effective materials and manufacturing methods are needed to meet the performance requirements for air-handling components at an acceptable cost.

EGR, which is being used to meet 2003 emission requirements, introduces corrosion of heat exchanger components (for cooling the EGR) and makes it necessary to increase the turbocharger boost to maintain the necessary oxygen partial pressure in the combustion chamber. The durability and fuel efficiency of the new 2003 engines may be a concern, and improved materials and designs for EGR systems are desired.

Better materials are needed for the linkage to control the variable-geometry turbocharger inlet and the wastegate valve, which operates at high temperatures (up to 600ºC) without liquid lubrication. In addition, lower-mass materials are needed for turbocharger rotors because the inertia of the turbocharger limits the ability of the system to respond rapidly.

The 50%-efficiency goal for a heavy-duty engine that meets the emissions reduction goals will likely involve higher specific power. The higher pressures require cost-effective materials with higher strength and fatigue resistance for engine blocks and cylinder heads, and either higher-quality cast iron or the use of high-strength materials to reinforce highly stressed areas in conventional cast iron components.

Higher peak cylinder pressures will also put additional stresses on pistons, liners, connecting rods, and crankshafts. Research is needed to evaluate the tribological characteristics of materials in piston-to-piston-ring and piston-ring-to-liner systems, bearings and bushings, and gear systems.

Selected insulation of hot-section and exhaust components to reduce heat rejection has been used to increase diesel engine efficiency to over 55% in a previous DOE research effort. Although efficiencies of up to 55% were demonstrated in a single-cylinder engine, the insulating materials used in the demonstration are not available as durable, cost-effective components. Research is needed to develop hot-section components with lower heat rejection.

Materials for durable valve train components in advanced engines will be necessary. R&D is needed to develop lightweight, wear- and corrosion-resistant valve train materials (valves, valve seats, valve guides, rollers, and rocker arms) for use in all classes of heavy-duty diesel engines. New concepts for joining dissimilar materials (e.g., intermetallic valve head to steel shaft) are needed to reduce the cost of new valve materials.

Cost-effective manufacturing processes also are necessary for the widespread commercialization of stronger, higher-temperature, corrosion-resistant materials such as superalloys, intermetallics, and ceramics. If advanced materials are to be commercially viable, new machining technologies must be developed for them.

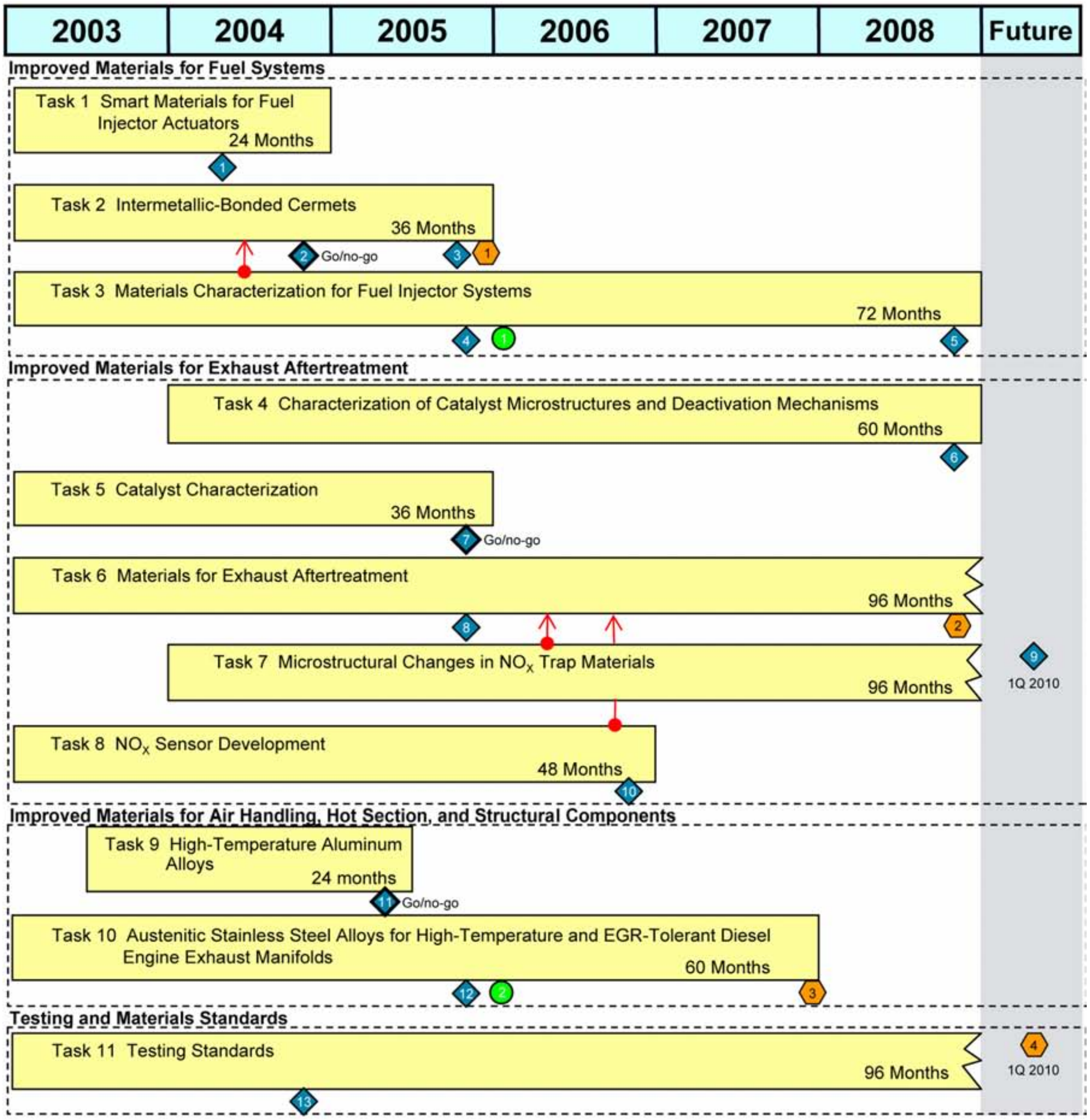
Testing and materials standards. Commercializing new materials will require extensive databases of materials properties. New design and testing methodologies will also be required. There will be an increasing need to simulate component performance and life to avoid expensive engine testing. New higher-resolution nondestructive evaluation techniques also will be required to ensure component survival during operation.

The commercialization of new materials and manufacturing processes depends on having standard testing methods that generate useful data for design and modeling and that are accepted by the industry. Materials testing standards in the United States are primarily voluntary consensus standards developed by the American Society for Testing and Materials (ASTM). ASTM standards are coordinated with international standards by the International Standards Organization (ISO).

Task Descriptions

The technical tasks are shown in Table 39.

Table 39. Tasks for Heavy Vehicle Propulsion Materials		
Task	**Title**	**Duration/ barrier**
Improved Materials for Fuel Systems		
1	Smart Materials for Fuel Injector Actuators • Evaluate new actuator technologies (dual- vs. single-actuator fuel injection), characterize materials requirements, and develop materials and processing for advanced actuators for better fuel injection control	24 months Barriers A, B, C
2	Intermetallic-Bonded Cermets • Develop Ni_3Al-TiC intermetallic-bonded cermets for applications in heavy-duty diesel fuel injection systems	36 months Barriers A, B, C
3	Materials Characterization for Fuel Injector Systems • Develop materials characterization and testing methodology to allow screening and evaluation of fuel injector component materials rapidly via bench tests	72 months Barriers A, B
Improved Materials for Exhaust Aftertreatment		
4	Characterization of Catalyst Microstructures and Deactivation Mechanisms • Conduct transmission electron microscopy studies of experimental catalyst materials subjected to simulated diesel exhaust in an ex-situ catalyst reactor system to determine catalyst durability • Conduct studies of model catalyst systems comprising heavy metal species on oxide supports to better understand the structures of catalytic materials from the atomic level	60 months Barriers A, B, C
5	Catalyst Characterization • Characterize crystal structure, morphology, phase distribution, particle size, and surface species of catalytically active materials supplied by CRADA partner using X-ray diffraction, Raman spectroscopy, and electron microscopy. Materials to come from all stages of catalyst's lifecycle: raw materials, as-calcined, sulfated, regenerated, etc.	36 months Barriers A, B
6	Materials for Exhaust Aftertreatment • Develop commercially viable catalytic materials and advanced aftertreatment technologies to reduce NO_X and particulates from diesel emissions to meet EPA 2007and 2010 standards	96 months Barriers A, B
7	Microstructural Changes in NO_X Trap Materials • Study microstructural changes that accompany the reaction of NO_X with trap materials (synthesized at Oak Ridge National Laboratory) under lean and rich conditions at high temperatures	84 months Barriers A, B
8	NO_X Sensor Development • Develop catalytically selective electrode materials that can be used for sensors that are selective to individual gas species for simpler, less expensive NO_X sensors	48 months Barriers A, B
Improved Materials for Air Handling, Hot Section, and Structural Components		
9	High-temperature aluminum alloys for high-efficiency, high-durability air-handling components in EGR environment. Creep, and low-cycle fatigue testing of diesel engine turbocompressor wheels of new high-temperature aluminum alloys	24 months Barriers A, B
10	Austenitic stainless steel alloys for high-temperature and EGR-tolerant diesel engine exhaust manifolds • Evaluate mechanical properties for operation in high-temperature and high-EGR exhaust manifold • Evaluate advanced stainless steels for high-temperature exhaust valve applications	60 months Barriers A, B
Testing and Materials Standards		
11	Testing Standards • Develop new ASTM testing standards for advanced materials • Develop new ISO testing standards for advanced materials	96 months Barriers A, B



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Milestone

1. Complete engine testing of primary injection system candidate for fast-response advanced engines. Decision point for feasibility of scale-up and commercialization
2. **Go/no-go** Complete engineering development of scuff-resistant, durable, and manufacturable Ni_3Al-TiC intermetallic cermets. Decision point for scale-up and commercial development
3. Complete scale-up and commercial introduction of Ni_3AlTiC fuel system components
4. Complete development of bench tests for scuffing and coating adherence
5. Correlate ranking system based on bench tests with ring or engine tests
6. New or improved catalyst system developed as a result of advanced characterization effort
7. **Go/no-go** Complete characterization of catalyst materials from all stages of catalyst life (provided by CRADA partners). Decision point for CRADA partners with respect to commercialization of catalyst to meet 2007 emission requirements

Milestone

8. Complete evaluation of materials/processing for microwave-regenerated particulate trap. Decision point for adoption of microwave assist for filter regeneration
9. Develop comprehensive understanding of catalyst deactivation mechanisms and corresponding microstructural changes
10. Determine commercial feasibility for catalytically selective electrode materials for low-cost NOx sensors
11. **Go/no-go** Complete creep and low-cycle fatigue evaluation of high-temperature aluminum alloy for diesel turbocharger compressor wheel. Decision point for scale-up to commercial scale
12. Complete development of austenitic stainless steel alloy for high-temperature air-handling components for advanced heavy-duty engine. Decision point for extending advanced stainless steels to hot-section components, such as valves
13. Complete current annex of International Energy Agency agreement and document progress. Decision point for development of new international collaborations to support FCVT

Technology Program Output

1. New, high-performance material available for heavy-vehicle fuel systems to meet fuel efficiency and exhaust emissions requirements of 2007 and beyond
2. Validated catalyst and particulate filter materials to enable fuel efficiency and emissions requirements to Advanced Combustion Engine R&D
3. Commercially available, cost-effective high-temperature stainless steels to Heavy Truck Engine R&D
4. Consensus standards (ASTM, SAE, ISO) for engineering transportation materials completed and available for use by industry

Supporting Input

1. Fuel specification for material compatibility study from Fuels Technologies
2. Material requirements from Heavy Truck Engine R&D

4.6.5 High Temperature Materials Laboratory

It is envisioned that the High Temperature Materials Laboratory (HTML) will play a critical role in assisting FCVT and HFCIT in realizing their goals by working with these programs' industrial and academic partners. These goals directly support the FreedomCAR and Hydrogen Fuel Initiative and the 21st CTP.

Goals

The HTML assists the industrial and academic partners in realizing the FCVT and HFCIT Program goals. The shared goals to which HTML contributes include these:

- Improve the efficiency of ICEs from 30 to 43% by 2010 for light-duty and from 40 to 55% by 2012 for heavy-duty applications while utilizing an advanced fuel formulation that incorporates a non-petroleum based blending agent to reduce petroleum dependence and enhance combustion efficiency.
- Reduce the weight of an unloaded tractor-trailer combination from the current 23,000 lb to 18,000 lb by 2010, a reduction in weight of 22%.
- Develop reliable systems for future hybrid fuel cell powertrains, with costs comparable to those of conventional ICE/automatic transmission systems. The powertrain will consist of a 60% peak-energy-efficiency, durable hybrid fuel cell power system (including hydrogen storage) at a cost of $45/kW by 2010 ($30/kW by 2015).
- By 2010, enable clean, energy-efficient vehicles operating on clean, hydrocarbon-based fuels powered by either internal-combustion powertrains or fuel cells.
- By 2010, enable the transition to a hydrogen economy by ensuring widespread availability of hydrogen fuels and retaining the functional characteristics of current vehicles, including hydrogen storage systems demonstrating an available capacity of 6 weight percent hydrogen, specific energy of 6 kWh/kg, and an energy density of 1.5 kWh/L at a cost of $4/kWh.
- Develop ICE powertrain systems that operate on hydrogen with a cost target of $45/kW by 2010 and $30/kW in 2015, have a peak brake engine efficiency of 45%, and meet or exceed emissions standards.

Programmatic Status

Through 2002, HTML had worked with customers on 1181 user projects, and it continues to attract new proposals at the rate of 75 to 100 per year. Users are mainly from universities, but U.S. industry is well represented, and other government laboratories also participate. User agreements through 2002 had been signed with 358 industrial concerns, 261 universities and colleges, and 23 other institutions. Projects have ranged across the materials topics that are of interest to DOE, from alloys and MMCs to advanced ceramics to electronic materials. In direct support of FCVT, HTML has developed four major research areas: Engine and Vehicle Materials; Emissions Reduction Materials; Materials for Hydrogen Generation, Storage, and Utilization; and Partnering with Industry.

Targets

HTML will assist FCVT and HFCIT in achieving their technical targets by making its unique user centers and expertise available to program participants.

Barriers

HTML provides materials expertise and unique facilities to address materials-related technical barriers that are elucidated in the previous sections describing the various R&D tasks of the Materials Technologies sub-program. HTML also works to overcome materials-related technical barriers to the success of HFCIT. The HTML User activity endeavors to assist in overcoming these barriers by supporting the universities, industries, and other governmental agencies involved in FCVT and HFCIT.

Approach

The technical approach taken by HTML and its User activity is to maintain state-of-the-art materials characterization facilities and equipment operated by skilled technical staff and provide them to users. The facilities and equipment typically are either one-of-a-kind items or provide a collection of characterization equipment in one facility that is unavailable elsewhere in the world. HTML provides access to such sophisticated equipment as atomic-resolution electron microscopes, synchrotrons, and neutron beamlines.

In 2003 and 2004, HTML will be receiving, setting up, and beginning experiments with the Aberration-Corrected Electron Microscope (ACEM), the first of its kind in the United States. ACEM is a state-of-the-art electron microscope that will provide sub-angstrom resolution, allowing the location and determination of individual atoms, such as those on automotive emission catalysts. Also, HTML staff will be working with staff of the Spallation Neutron Source to locate an instrument called VULCAN on one of its beamlines. VULCAN will allow residual stresses to be measured on articles such as engine components at higher resolutions and speeds than is now possible anywhere. VULCAN will also be extremely sensitive to hydrogen atoms, making it useful for determining hydrogen storage mechanisms.

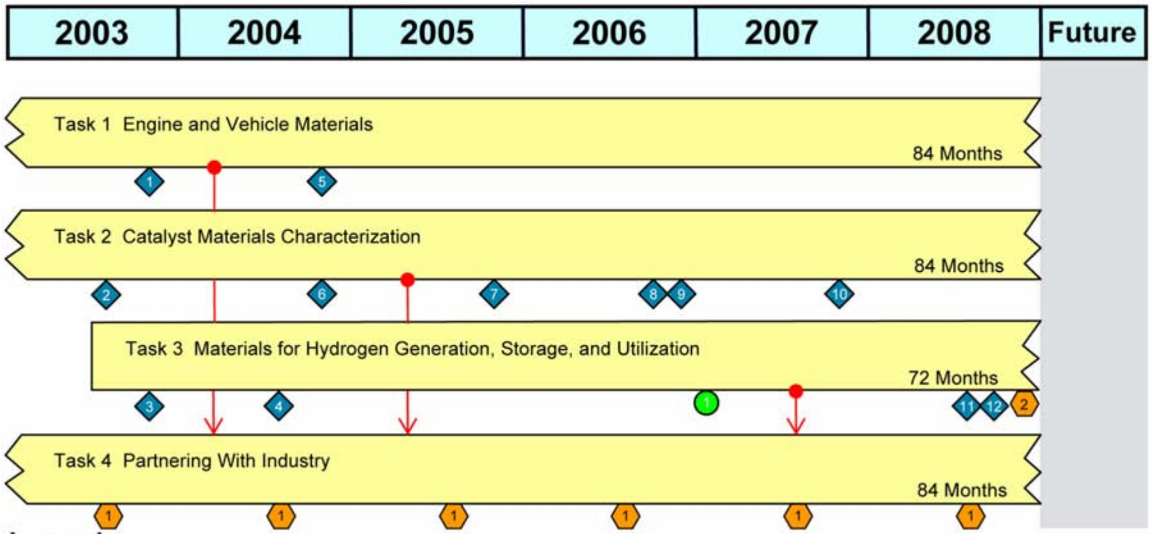
Task Descriptions

A description of each technical task, along with the estimated duration and technical barriers associated with the task, is provided in Table 40.

Table 40. Tasks for High Temperature Materials Laboratory		
Task	**Title**	**Duration/ barriers**
1	Engine and Vehicle Materials • Characterize the mechanisms of interaction and the properties of an interface or joint formed between two lightweighting materials • Collaborate with FCVT industry partners and technical teams to determine and characterize materials-related life-limiting mechanisms and failure modes of engine system components • Assist FCVT industrial and academic partners in developing advanced materials and processes for engine and vehicle components	84 months
2	Catalyst Materials Characterization • Identify and characterize mechanisms of functioning and degradation of lean-burn engine emission control catalysts • Assist FCVT industrial and academic partners in developing advanced materials and processes for emissions reduction components • Assist FCVT and HFCIT industrial and academic partners in developing advanced, low-cost catalysts and processes for emissions control, fuel cells, and hydrogen generation	84 months
3	Materials for Hydrogen Generation, Storage, and Utilization • Resolve storage sites within a high-hydrogen density storage material • Assist FCVT and HFCIT industrial and academic partners in developing advanced materials and processes for fuel cells, and hydrogen generation, storage, distribution, and use	72 months *(begin 3Q 2003)*
4	Partnering With Industry • Develop and maintain the state-of-the-art science and tools required to characterize advanced materials of interest to FCVT and HFCIT and their partners • Support a robust user community specifically including the automotive and heavy–vehicle industries, supporting industries, and materials characterization requirements of other EERE partners	84 months

Milestones

The HTML activity milestones are shown in the following network chart.



Legend

Milestone

1. Characterize the structure and durability of joints formed between conventional aluminum components by two low-temperature alternatives to molten welding
2. Correlate measured performance to HTML characterization results on a commercially available diesel engine emissions control catalyst
3. Initiate a user effort characterizing hydrogen storage in an absorption media
4. Use HFIR neutron beam to perform a hydrogen resolution experiment set up in Q3 of 2003 and initiate the Spallation Neutron Source experiment design
5. Characterize the structure and durability of joints formed between two otherwise intractable aluminum metal matrix composites
6. Identify and characterize mechanisms of functioning and degradation of lean burn engine emission control particulate and NO_x traps
7. Commission AMCL, showing that it provides environmental conditions necessary to support advanced electron microscopes
8. Use ACEM in the study of an experimental NO_x trap material, showing imaging capabilities not possible using any present-day microscopy capability at ORNL
9. Launch commissioning of VULCAN
10. Study 2 experimental diesel NO_x-reduction materials using a combination of HTML's ex situ catalyst reactor for TEM specimens and the imaging and spectroscopy of ACEM
11. Demonstrate the utilization of the Spallation Neutron Source (VULCAN) for time-resolved in-situ characterization of hydriding-dehydriding of hydrogen storage materials
12. Correlate atomic-level structure of a hydrogen-storage material, determined by ACEM, with structural phenomena revealed using neutron beams, to elucidate storage mechanisms

Technology Program Output

1. User project report to all partners
2. Characterization and technology related to atomic level understanding of hydriding and dehydriding of storage materials available to industry and HFCIT

Supporting Input

1. Candidate hydrogen storage materials from HFCIT