3.4 Materials Technologies

The Materials Technologies subprogram aims to develop and validate advanced materials and manufacturing technologies that support achievement of the FreedomCAR and 21st Century Truck Partnership goals. The weight reduction and propulsion material technologies pursued in this endeavor address the critical materials needs for body, chassis, and powertrain systems for cars, light trucks, commercial vehicles, and buses. This represents a complex matrix of performance, duty cycle, volume, and market constraints that are factored into all aspects of subprogram planning. The broad scope of materials and processing technologies that are addressed in the subprogram is equally diverse and includes metals, polymers, and composites. Materials advancements are an integral factor in addressing the technical and cost barriers, as well as being critical to addressing the overarching energy, economic, and environment objectives of the FCVT Program.

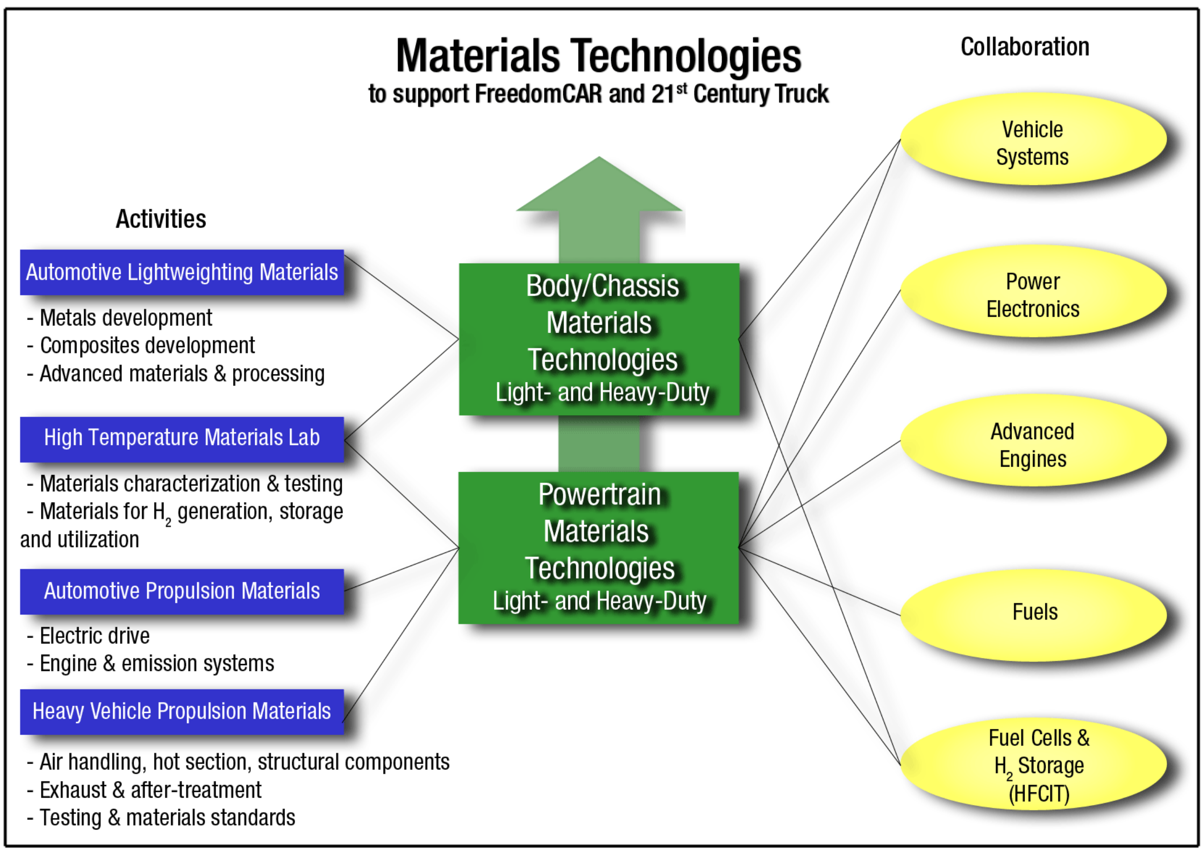


Figure 3.4-1. Materials Technologies Subprogram

The Propulsion Materials activity is focused on engine and electric drive system materials needs and establish their requirements through collaborations with Power Electronics, Advanced Combustion Engines, and the Fuels Technologies activities. The Automotive Lightweighting Materials activity provides technologies that can meet the weight savings goals of the industry partnership. Figure 3.4-1 describes the relationship of the Materials Technologies subprogram within the larger FCVT Program.

3.4.1 External Assessment and Market Overview

Materials used in the production of personal and commercial vehicles are varied and often highly specialized. Automotive OEMs compete to provide economically attractive materials solutions for their customers, such as improved performance or innovative features. This applies to technologies that reduce mass as well as those powertrain technologies that improve engine or electric drive system efficiency and overall operational system effectiveness. Although aluminum, magnesium, and polymer composites have made inroads in recent years and advanced high strength steels have reclaimed some market share, iron and steel are presently the dominant materials in car and truck manufacturing. Raw material price and supply patterns resulting from growth in emerging markets, such as China, are having a profound impact on global materials demand and costs.

Industrial automotive materials research doesn't always support DOE's mission, and is highly focused on near-term goals. External to DOE, materials research is often aimed at improving functionality, reducing part costs, or reducing assembly time. These objectives are sometimes, but not necessarily, coincident with DOE's energy savings objective. Within the automotive and commercial vehicle manufacturers, the focus is on materials and processing technologies that are needed for current vehicles or their immediate successors. The time horizon for research results can be as short as 1 to 3 years. Longer term research must have tremendous potential for cost savings or deliver vitally needed new capabilities in order to be supported by automotive OEMs. The best opportunities for introducing advanced materials technologies are in materials cost reduction, improved processing, and parts consolidation. A vast pool of suppliers and manufacturers of automotive components support this materials development and supply system. Incremental improvement in materials technologies is the norm.

The Materials Technologies subprogram works to provide materials solutions that address industry's desire for reduced cost, while meeting national objectives for improved fuel economy.

3.4.2 Internal Assessment and Subprogram History

The Energy Policy Act of 1992 authorized development of improved materials having superior properties and performance characteristics. Timely availability of new materials and materials manufacturing technologies will enable the development and engineering of more energy efficient vehicle technologies and allow the U.S. transportation sector to move away from its near-total dependence on petroleum, a major goal of the EPAct, and more currently, of the National Energy Policy (NEP) of 2001.

Since its inception in 1990 (under the Office of Transportation Technologies/Office of Transportation Materials), the Materials Technologies efforts have focused, in general, on two categories of materials: 1) propulsion system materials, that can improve the efficiency of engine and electric drive system components; and 2) lightweight materials, for improving fuel economy by reducing vehicle weight. In addition, highly specialized instrumentation for research and characterization of these advanced materials is essential. The High Temperature Materials Laboratory (HTML) is FCVT's primary research center for providing these tools and services to a user community of individual companies, universities, and other research institutions.

In preceding decades, the program primarily focused on emerging ceramics for automotive gas turbines and low-heat-rejection heavy-duty diesel engines. These two prime movers have since been removed from the transportation research portfolio. In response to the evolving technology needs of the automotive sector and the R&D goals of DOE, the Materials Technologies subprogram was diversified to also address lightweight body materials, as well as propulsion system materials for automotive and commercial vehicle applications. This diversification has served to enhance the crosscutting applicability of advanced transportation materials to other EERE programs for industrial process efficiency and fossil energy conversion.

Examples of successes from the Materials Technologies subprogram include:

- ***Super/"Quick" Plastic Forming.*** DOE's Pacific Northwest National Laboratory, General Motors, and Kaiser Aluminum cooperatively developed an alloy that showed promise in reducing forming times, costs, and material weight. GM integrated the technology into the rear liftgate of the 2004 Chevrolet Malibu Maxx.
- ***Rapid Infrared Curing Process.*** This joining/braising and resin-curing process for seam joints in production vehicles was developed jointly by Ford and Oak Ridge National Laboratory (ORNL). It replaces the weld and thermal spray process, saving time and about $28 per vehicle. Additionally, it consumes less energy and is more environmentally safe. With less porosity in the coating, this technique eliminates extra surface preparations.
- ***Lightweight Tie Rod for Heavy Trucks.*** ORNL and Delphi Corp developed structural chassis components for Class 8 trucks using carbon fiber reinforced composites. These tie rod ends save over 60 percent of the mass compared to steel and have improved corrosion resistance, durability and load capacity.
- ***Structural Cast Magnesium Development.*** A DOE and U.S. Automotive Materials Partnership (USAMP) produced a prototype magnesium casting for a 2006 model year GM Corvette Engine Cradle. This cradle is 35 percent

lighter than the previous model and has been incorporated into the 2006 Corvette production line.

3.4.3 Federal Role

The transportation sector of the U.S. economy is a prodigious consumer of petroleum and the on-road segment of this sector accounts for the largest portion of that usage. Thus, the DOE has identified consumption of petroleum in transportation as a key target for Federal attention in order to reduce the use of oil, decrease the balance of payments deficits, increase national security, and improve air quality.

The role of the Federal government in achieving these goals, through advanced materials R&D, is based upon the enabling role played by materials in realizing increased fuel efficiency through lighter weight vehicles and more efficient powertrains. More explicitly, the Federal role is to support high payoff R&D which the private sector views as an unmanageable risk. The historically long timeline required for introduction, development and commercialization of new materials precludes initiation of an exploratory effort at the time that the material is already needed in the marketplace. The R&D phase for advanced materials must anticipate the technology needs and proceed in a timely fashion to mesh with commercial requirements. This materials research and development timeline is virtually always too long for the OEM's to undertake without some sharing of the risk, especially in periods when severe market and competitive conditions impact the availability of research funding.

Additionally, there are outcomes from Federal R&D involvement that provide a beneficial effect. In the first, expression of interest by DOE in a technology often motivates private companies to reconsider their own internal technology assessment and encourages them to seek collaborative efforts with DOE through various mechanisms. The second benefit of Federal research activity is the combination of unique capabilities, equipment, or technologies at the national laboratories that industry can make use of, with suitable modification. In this instance, the Federal investment in the original technology is greatly leveraged by the potential commercial value, though it may originally have had completely different purposes. A third Federal role emerges where a segment of the transportation sector identifies technical opportunities in energy saving materials but is under-funded and cannot invest in the required research to mature the technologies (particularly for long lead time, higher risk concepts). Depending on the outcomes of appropriate cost-benefit analyses, DOE can seed the research in these areas and participate in the technology development with industry with possible later licensing fees and royalties returning value to the Federal establishment for its earlier risk taking.

In summary, the Federal role of materials research is to support the nation's energy goals by partnering with the technical community in the development of new and improved materials, material processes, and innovative component designs that enable the development of commercially viable, fuel efficient vehicles.

3.4.4 Approach

The Materials Technologies subprogram uses a structured approach to planning and implementing R&D. Technical areas of importance are primarily identified and defined through interactions within the transportation stakeholder community, often at focused workshops. At these facilitated meetings, the goals of FCVT are described, the materials technology barriers to meeting those goals are identified, and a consensus multiyear work plan that addresses the barriers is formulated. Projections of performance period and required financial resources are also made and included in the draft documents which are then circulated for peer review and comment prior to publication. Project selection is primarily through competitive procurements directed at cost-shared industrial efforts. Supporting industry/national lab Cooperative Research and Development Agreements (CRADA) and university agreements are selected by the Department as necessary, along with directed R&D at DOE labs. In the case of the automotive materials research, the light duty automotive companies participate in R&D prioritization by means of industry-government technical teams. A similar, but less formalized, methodology is employed by the heavy vehicle stakeholder partnership. Through this approach, industry provides a real world technology baseline for the Federal research community and that community provides innovative technical opportunities to industry. The ultimate outcome is a collaborative effort that achieves the nation's transportation energy goals as surely and quickly as the marketplace and innovation allow. This approach is the best option suited for eventual transfer of the materials technology into the private sector.

To remain at the leading edge of advanced materials characterization technology, HTML continually surveys industry and academia in order to determine the equipment and facilities which are needed, and conducts competitive selection of supported research proposed by external users. Proposals for user agreements are reviewed and selected by HTML staff based on a set of objective criteria. An industrial advisory committee reviews HTML user program annually and provides feedback on the program. In addition, HTML queries the user community for input on advanced tools and characterization assets which it needs in order to retain world-class prominence.

Materials Technologies is subdivided into two focus areas: lightweight materials and propulsion materials, each of which is divided into major technical thrust areas (projects). The High Strength Weight-Reduction activity, which focused on light weight materials for heavy trucks, has been discontinued in order to channel materials resources into more energy intensive research activities. An additional activity covers the advanced materials characterization function provided by HTML. The key activities for the Materials Technologies subprogram are:

- Lightweighting Materials
    - Automotive Lightweighting Materials
- Propulsion Materials
    - Automotive Propulsion Materials
    - Heavy Vehicle Propulsion Materials
- High Temperature Materials Laboratory

Technical risk analysis is an integral part of the materials program planning and evaluation process. A number of formal and informal processes are used to vet new projects, evaluate the viability of ongoing work, and to balance the portfolio in terms of risk, timeframe addressed, technology maturity, and other dimensions.

- Quantitative benefits analyses are performed for each technical thrust area (aluminum, low-cost carbon fiber, composites processing, and recycling, have already been completed) on an ongoing basis. These are performed by laboratory technical staff, and by independent consultants.
- Standard portfolio analysis tools are applied to the activities to evaluate their risk, estimate mission impact, identify new opportunities, summarize threats, and provide viable off-ramps. This process has been applied to the Heavy Vehicle Propulsion Materials area and will expand to the other areas as well.
- The FreedomCAR Materials Technical Team provides an exhaustive review of new project proposals for the Automotive Lightweighting Materials area. Ongoing projects are also reviewed regularly and new technical thrusts are reviewed by automotive and independent technical experts. This process is ongoing and addresses all the major technical thrust areas in the subprogram.
- Feedback from peer reviews is used to support program planning and project direction decisions.

Through a combination of these processes and tools, the Materials Technologies subprogram maintains a balanced, robust portfolio of long term, potentially high payoff research and mid-term, moderate risk technology development that supports the FCVT interim strategy.

3.4.5 Performance Goals

The FCVT Materials Technologies subprogram seeks exploratory and applied research, development and validation of advanced materials, and processing technologies that support the achievement of overall program goals. Because of the broad scope of technologies needed to address weight reduction, improved manufacturability and performance enhancement, the subprogram is branched into the four activities listed above.

Key performance goals in these activities are cited below. Technical Targets are included and are consistent with the measures identified in Section 2.4.

Automotive Lightweighting Materials
The Automotive Lightweighting Materials activity is focused on structural materials for body and chassis applications that can significantly reduce vehicle weight of passenger vehicles without compromising vehicle lifecycle cost, performance, safety or recyclability. The specific goals and technical targets for the Automotive Lightweighting Materials activity are:

By 2012, develop and validate advanced material technologies that will:
- Enable reductions in the weight of body and chassis components by at least 60 percent and overall vehicle weight by 50 percent (relative to 1997 comparative vehicles);
- Exhibit performance, reliability, and safety characteristics comparable to those of conventional vehicle materials; and
- Enable commercially available aluminum, light metal alloys, high strength steels, and glass- and carbon fiber reinforced composite materials with lifecycle costs equivalent to conventional steel.

Table 3.4-1. *Technical Targets: Automotive Lightweighting Materials*

Characteristics	Year	
	Baseline	2012
Weight of Body in Pounds	1250	580
Aluminum sheet cost per pound	$1.70	$1.20
Aluminum manufacturing and assembly savings relative to steel per body	–$250	$0
Aluminum body life-cycle cost relative to steel[a]	1.5×	1×
Glass-fiber-reinforced composite body life-cycle cost relative to steel[a]	1.2×	1×
Carbon composite mfg and assembly savings relative to steel per body	•$300	$100
Carbon-fiber-reinforced body composite life-cycle cost relative to steel	3×	1×
Weight of Chassis in Pounds	940	425
Glass-fiber-reinforced composite chassis life-cycle cost relative to steel[a]	1.2×	1×
Carbon-fiber-reinforced chassis composite life-cycle cost relative to steel	3×	1×
Weight of Propulsion Subsystem in Pounds[b]	860	750
Weight of Fuel Subsystem in Pounds[b]	190	85
Total Vehicle[a] Weight in Pounds	3240	1840

[a] For production volumes greater than 100,000 per year.
[b] The ALM technology activity addresses only body and chassis weight; propulsion subsystem and fuel subsystem weight are included for reference only and are addressed elsewhere in the plan.

As stated in Section 2.4, there are a number of materials and measures involved in this goal. One priority measure has been identified and tied into the Department Joule system which is the cost of carbon fiber in dollars per pound. In 2004, a study was performed by Kline and Company to assess the status of carbon fiber cost. That study confirmed that the DOE R&D effort was on track to meet its target.

Automotive Propulsion Materials

The technical goals of the Automotive Propulsion Materials activity support the targets of the Advanced Power Electronics (Section 3.2, Table 3.2-9) and Advanced Combustion Engine (Section 3.3, Table 3.2-1) activities. Supplementary Automotive Propulsion Materials specific goals and technical targets include the following:

- By 2009, develop advanced, cost effective valve materials for HCCI engines through computational design approach.
- By 2011, develop advanced materials for hydrogen engines that have improved wear resistance and durability.

Table 3.4-2. Technical Targets: Automotive Propulsion Materials

Automotive Propulsion Materials	Technical Targets
HCCI Engine valve material composition	Complete computational modeling and experimental validation (by 2007)
Materials for Hydrogen internal combustion engines	Increase the wear resistance and durability of materials for H2 injectors (by 2006)

Heavy Vehicle Propulsion Materials

The Heavy Vehicle Propulsion Materials activity is primarily aimed at applications in Class 8 trucks as they consume more fuel annually than Classes 3 through 7 combined. Similar to the Automotive Propulsion Materials area, the plan for the Heavy Vehicle Propulsion Materials activity focuses on the technologies and issues for advanced materials used in diesel combustion and aftertreatment systems.

The specific goal and technical targets for the Heavy Vehicle Propulsion Materials activity are:

- By 2012, develop the supporting materials technology required to enable prototypical heavy-duty engine efficiency of 55% while meeting prevailing EPA emissions standards.

***Table 3.4-3.** Technical Targets: Heavy Vehicle Propulsion Materials*

Heavy Vehicle Propulsion Materials	Heavy Vehicle Engine Technical Targets
Fuel system materials	Efficiency greater than 50% (by 2007)[a]
Materials for air-handling, hot-section, engine structures	Engine life greater than 1 million miles (by 2012)
Exhaust aftertreatment materials	Compatible with future fuels, performance and durability consistent prevailing EPA regulations (by 2010)

[a] The baseline engine efficiency for heavy duty diesel engines is 40%.

High Temperature Materials Laboratory
HTML contributes to the achievement of all the above materials goals by providing expert materials characterization and analysis equipment, expertise, and services. HTML also assists the industrial and academic community throughout the transportation industry in realizing the FCVT and HFCIT Program goals.

- By 2008, utilize HTML large specimen residual stress facilities (VULCAN beamline on the Spallation Neutron Source [SNS], the NRSF2 at High Flux Isotope Reactor [HFIR], and/or the large specimen X-Ray Diffraction [XRD] system) to perform a User Project with an industrial partner to determine the origin of and techniques for minimizing residual stresses developed in an automotive engine or structural component made from a lightweight material such as aluminum, titanium, or magnesium.

3.4.6 Strategic Goals

The strategic goals of the Materials Technologies subprogram are to:

- Increase the fuel efficiency of passenger vehicles through increased utilization of lightweight materials;
- Improve the efficiency of advanced engines through innovative material solutions; and
- Maintain and enhance the world class materials characterization, analysis, and testing capability at HTML.

3.4.7 Market Challenges and Barriers

A. ***Cost.*** Prohibitively high cost of finished materials is the greatest single barrier to the market viability of advanced lightweight materials for automotive and commercial vehicle applications.

B. ***Inadequate supply base.*** The manufacturing and materials supply base does not currently exist to support widespread deployment even on a modest scale, especially for polymer composites and magnesium. The entire materials supply chain and production industry will need to expand dramatically in order to effectively introduce fuel savings benefits in the ground transportation arena by 2012.

3.4.8 Technical (Non-market) Challenges and Barriers

C. ***Design data and modeling tools.*** 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. ***Manufacturability.*** Methods for the cost-competitive, high-volume production of automotive components from advanced lightweight materials do not exist. 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. Advanced materials, by virtue of their unique physical and mechanical properties, are often difficult to manufacture with current technology in production quantities and with the required precision and reproducible quality.

E. ***Tooling and prototyping.*** The cost of tooling for forming components made with lightweight and propulsion 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.

F. ***Joining and assembly.*** High-volume, high-yield joining technologies for lightweight and dissimilar materials do not exist. Non-destructive techniques for the evaluation of the integrity of joints are not sufficiently developed.

G. ***Performance.*** Materials needed to achieve the performance objectives in specific engine and ancillary components may not exist today as durable, reliable, well-characterized and understood materials.

H. ***Maintenance, repair, and recycling.*** Technologies for cost-effective recovery of high value materials from end of life vehicles and, maintenance and repair of advanced materials, especially carbon-fiber reinforced composites, do not exist.

3.4.9 Strategies for Overcoming Barriers/Challenges

Technologies will be pursued that can potentially reduce the cost of feedstocks, and the cost of manufacturing of lighter-weight structural components. These technologies include:

- *Carbon fiber*–Research will be pursued that seeks to use new classes of precursor feedstock for fibers and provide the tools for precursor scale up. These will displace current reliance on pitch and polyacrylonitrile (PAN) precursors that carry an initial cost premium. Processing methods will be developed for significantly reducing the cost of producing carbon fiber include microwave carbonization, radiation stabilization, plasma oxidation, and improvements in line speed and reduction in 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 processing technologies in a pilot line technology demonstration environment.

- *Primary metal production*–Research will focus on the basic methodologies for cost-effectively producing primary light metals (aluminum, magnesium, and titanium) that currently 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. There is a crosscutting link with EERE Industrial Technologies Program here.

- *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.

- *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 and wrought alloys that offer potential for improved properties.
- *Metal matrix composites (MMCs)*–Research opportunities to reduce the cost of reinforcing materials, matrix materials, and preforms will be evaluated. Rapid, near net shape casting technologies will also be developed.

Inadequate Supply Base. DOE will work within industrial partnerships to advance the knowledge and experience base for composite materials and other less mature markets to ensure that technological progress has a potential supplier base to receive it.

Design Data and Modeling Tools. To best take advantage of the properties of polymer composite and lightweight metals in 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:

- Particulate matter reductions–The 2007 and 2010 EPA particulate matter regulations will likely require the use of particulate filters. There are concerns about the durability of the brittle, porous ceramic filters. Activities are ongoing to develop the characterization and life-prediction modeling tools needed to realistically assess the expected life of the particulate filters.
- 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.
- Crash 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.

- 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. The development of life prediction methodology and data will be needed for critical hot section components as well.

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:

- Near net shape–Near net shape manufacturing has the potential to effectively eliminate costly intermediate steps involving machining of materials into dimensionally tolerant parts. Generally associated with casting or other forming processes, near net shape processing is linked to the design methodologies and material data barrier because of the fundamental material behaviors that must be understood and accounted for (e.g., shrinkage with cooling or desiccation). Coupling this research into tooling and prototyping constitutes a contributing sub-strategy for manufacturability.
- 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 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.
- Low-temperature combustion–LTC technologies introduce new demands on fuel systems, including the need for much improved spray patterns and multiple injections, which may require improved manufacturing technology for fuel injectors with smaller and more precise holes, in larger numbers, and for faster and more precise actuators. Improved high-precision manufacturing and inspection methods for the injector components will be developed
- Metal Matrix Composites–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.

Tooling and Prototyping. The introduction of advanced polymer-based composite and lightweight material manufacturing processes to vehicle manufacturers and their supplier base is severely impacted by the high cost of tooling development time. This is particularly true for commercial vehicles where lower production volumes make current tooling design and development methods unsuitable. The status and need for low-cost tooling technologies for lightweight materials will be assessed. In addition state-of-the-art capabilities for rapid, low-cost tooling approaches will be evaluated. Socioeconomic factors that are likely to significantly impact the development and implementation of advanced tooling technology will be determined and selected R&D to address these issues will be initiated.

Joining and Assembly. 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.

Performance. Throughout the engine and powertrains of both commercial and personal use vehicles, improved materials and manufacturing technologies can enable higher system efficiency improved durability. The following improvements in propulsion systems will be pursued:

- Due to the reduction in fuel sulfur and subsequent reduction in lubricity, both fuel and oil additive packages may change. The effect of new additives on aftertreatment devices will be investigated and characterized.
- Better materials are being developed for the variable-geometry turbocharger inlet and the wastegate valve. 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.

- Thermal control will become increasingly important in LTC engines, as the LTC processes are very sensitive to temperature. Improved understanding and control of wall heat transfer will be necessary, especially during transients. In addition, the performance of heat exchangers, such as radiators and intercoolers, will be enhanced through a systems approach including improved design, construction materials and heat transfer medium. Advanced materials with high thermal conductivity and corrosion resistance will be developed.
- The ambitious fuel efficiency goals adopted for 2012 will require a substantial reduction in the parasitic energy losses due to heat transfer to the engine coolant. Research is needed to develop hot-section components with lower heat rejection.
- Structural components in engines include the engine block, cylinder head, crankshaft, camshaft, connecting rods, manifolds, and assorted shafts, bushings, and housings. Lighter weight, higher strength materials will be required for many of the engine structural components in order to meet the 55% efficiency goal. Significant weight savings will be realized in heavy duty engines by substituting lightweight materials, such as titanium, aluminum, and magnesium.
- Thermoplastic resin systems—Technologies will be developed for increasing the performance properties of less costly thermoplastic systems by 10–30%.

Maintenance, 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.

3.4.10 Element Tasks

***Table 3.4-4** Tasks for Automotive Lightweighting Materials*		
Task	**Title**	**Duration & Barriers**
1	***Automotive Metals Research and Development*** Phase 1 (Completed)	36 months Barriers A, C,D
	Phase 2 • Complete development and optimization of electroforming technologies for aluminum • Complete development of formability models for weld metal in tailor welded aluminum blanks • Develop test methods, constitutive materials models, and finite-element analysis guidelines for simulation of crash energy absorption of high-strength steels • Conduct fundamental studies of magnesium, deformation, corrosion, creep behavior, etc. • Develop enhanced powder consolidation technologies and demonstrate > 98% theoretical density for low-cost titanium powder feedstock	48 months Barriers A, C, D
	Phase 3 • Evaluate and develop alternative technologies for low-cost processing of sheet aluminum alloys, e.g. spray rolling, for automotive applications • Optimize forming and joining technologies for transformation-induced-plasticity (TRIP) steels • Develop warm-forming technology for magnesium sheet • Develop low-cost manufacturing and machining processes for titanium components, including direct casting of titanium bar and rod products • Develop technologies for cost-effective fabrication and assembly of advanced metal components • Develop models for prediction of the response of metallic components to deformation during forming and during use • 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 • Develop technology for low-cost magnesium metal matrix composite (MMC) • Evaluate low-cost Mg sheet produced by twin roll casting techniques • Develop compositional variants of magnesium alloys to optimize properties • Investigate nano-reinforced MMCs for automotive applications	48 months Barriers A, C, D, G

	Phase 4 • Develop low-cost continuous casting technology for production of high-quality 6××× series aluminum sheet for application in outer panels • Develop innovative shaping technologies (impact forming, electohydraulic forming, high speed machining and technologies for casting ultra-large components) • Demonstrate integrated titanium reduction-to-wrought product process using low-cost powder production, combined with continuous hearth melting and rod rolling.	36 months Barriers A, C, D, D
2	***Polymer Composite Research and Development*** Phase 1 (Completed)	42 months Barriers A, D
	Phase 2 • Developed a design database and design methodology for thermoset and thermoplastic carbon fiber composites, including durability and processing parameters (Completed) • Develop rapid thermoplastic processing technologies and begin development of commercially viable predictive models for thermoplastics.	54 months Barriers A, C, D
	Phase 3 • Develop processing predictive modeling tools for long fiber thermoplastic injection molding. • Optimize discontinuous fiber composite processing technologies to achieve realistic production speeds, quality, and cost-effectiveness. • Develop fiber surface treatments and polymer modifications to optimize fiber/resin compatibility in natural fiber reinforced composite systems. • Develop a structurally and economically viable carbon fiber SMC material. • Complete a demonstration that integrates all of the thermoplastic composite and advanced reinforcement development research to demonstrate technical and economic viability of the technologies • Develop non-thermal methods for cross-linking thermoplastic resins with and without reinforcements • Develop a design database and design methodology for thermoplastic automotive fiber-reinforced composites, including durability and processing parameters for glass fibers, carbon fibers, or other advanced reinforcements • Develop predictive modeling tools for polymer composite property retention • Develop the processing capability to combine rapid preforming with thermoplastic resins to accomplish preforming and molding on one machine, followed by thermoforming	42 months Barriers A, C, D
	Phase 4 • Develop natural fiber composites reinforced with nano-filler materials • Develop the processing capability to combine rapid preforming technology for carbon fibers, natural fibers, and/or glass to make hybrid material automotive preforms that achieve automotive production rates and 2.0-mm thickness • Develop advanced polymer reinforcing fibers and micro-particle composite reinforcement technologies • Begin processing studies using advanced polymer fibers as reinforcements. • Develop a class “A” quality carbon fiber based SMC materials that is economically viable. • Demonstrate processing of low viscosity thermoplastic resin systems for liquid – molded perform composites.	60 months Barriers A. D

3	***Low-Cost Carbon Fiber*** Phase 1 (Completed)	36 months Barriers A, B, D
	Phase 2 (Completed)	48 months Barriers A, B, D
	Phase 3 • Develop a carbon-fiber research user facility • Complete development of novel precipitation purification/recovery process for lignin-based precursors for low-cost carbon fiber. • Develop non-thermal methods for stabilizing and oxidizing carbon-fiber precursors, including lignin-based forms, while demonstrating technical and economic feasibility • Complete development of advanced stabilization and oxidation methods. • Complete full scale development of lignin based precursors in a large tow format at production line rates with acceptable material properties.	48 months Barriers A, B
	Phase 4 • Validate scaled-up processes for carbon fiber production through economic and technical analysis • Assist industry in implementing the new technologies.	36 months Barriers A, B, D
4	***Miscellaneous*** Phase 1 Completed	60 months Barrier C
	Phase 2	48 months Barrier C
	Phase 3 • Develop understanding of the effect of strain-rate-dependent materials on crash energy absorption capabilities • Develop technologies for lightweight, cost-effective alternatives to glass closure panels • Develop a crash energy management design database for magnesium alloys and structures • Develop test methodologies for measuring response of advanced automotive materials to impact loading. • Develop unique test methods for measuring material parameters and for real-time validation of crack formation kinetics. • Through modeling and analysis, verify that technologies developed will yield >50% weight reduction of body and chassis	48 months Barrier C
	Phase 4 • Develop methods for accessing the system level durability of automotive systems that are comprised of both metal and composite components. • Include the response of component joints in the system level crash models. • Develop a liquid-molded, laminated window sideglass with nano-particulate modified interlayer for thermal control	36 months Barrier C
5	***Material Recycling and Repair*** Phase 1 (Completed)	36 months Barrier H

	Phase 2 Develop recovery processes for separating the high-value fiber from the resin (Completed) Provide recycled fiber for process trials (Completed) Extend aluminum scrap-sorting technologies to other light metals, such as magnesium and titanium 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	60 months Barrier H
	Phase 3 Develop technologies for repair of structural/safety components Develop technologies for recycle of metal matrix composites, high-strength steels, and other advanced materials. Define technology and infrastructure requirements for the recycle, remanufacture and repair of advanced lightweight components and systems for advanced vehicular designs (e.g. hybrids and hydrogen fueled vehicles)	36 months Barrier H
6	***Joining*** Phase 1 (Completed)	42 months Barriers A, F
	Phase 2 (Completed)	42 months Barriers A, F
	Phase 3 • Develop techniques for friction stir spot welding of advanced high strength steels (AHSS) • Evaluate fatigue properties of friction stir welds in high strength steels and validate properties against resistance spot welding. • Develop test methodologies and computer simulation of performance of resistance spot welds under impact loading conditions • Develop innovative joining technologies • Develop designer-usable joint models to aid structural engineers in designing joints for weight reduction and occupant safety optimization • Demonstrate joining technologies for application to joining of different product forms, e.g., hydroformed tubes to castings • Demonstrate resistance spot weld nugget control using real-time integrated ultrasonic electrode transmission and analysis techniques. • Develop joining and assembly technologies to ensure adequate dimensional control.	36 months Barriers A, C, F
	Phase 4 • Develop predictive models for dimensional control of welded assemblies • Develop aluminum rivets for joining of aluminum components • Develop rapid and efficient methods for welding thermoplastic materials. • Integrate all joining-related tasks into demonstrations that highlight the benefits of all technologies developed earlier and demonstrate industry-acceptable assembly, real-time control, and enhanced environmental effects.	36 Months Barriers A,C, F
7	***Non-Destructive Evaluation*** Phase 1 Completed	36 months Barriers C, F

	Phase 2 • Develop NDE techniques for real-time inspection and control of adhesive bonds and resistance spot welds • Develop on-line and near-real-time nondestructive evaluation methods for inspection of joining processes to determine bond quality and quantify defects	42 months Barrier F
	Phase 3 • Develop nondestructive evaluation processes for fiber-reinforced-composite and metallic components and installed parts, including predictive performance capability • Develop nondestructive evaluation methods to measure and/or verify lay-up of fibers, resin fill, resin infiltration, fiber wetting, and curing for polymer composites	24 months Barrier F
8	***U.S. Automotive Materials Partnership Cooperative Agreement*** Phase 1(completed)	36 months Barriers A, C, D
	Phase 2 • Develop models for processing of powder metals (PM) and prediction of performance of PM components. • Develop coating technologies to improve corrosion and wear resistance of magnesium alloy components • Conduct validation tests on cast magnesium structural and powertrain components • 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 • Expand composite material crash models to include the effects of environment, processing parameters, design parameters and load histories. • Expand composite material crash models to include the effects of manufacturing variability and system usage variabilities. • Develop tooling and demonstrate key component technologies enabling at least 50% weight reduction for body and chassis components • Complete development of advanced forming technologies such as hydroforming, warm forming, and variable binder control for aluminum components • Develop technologies for forming Mg sheet components with Class A surface for exterior applications including coatings. • Extend investigations of the forming technologies for advanced high-strength steels for front-end structures to the passenger compartment and rear-end structure • Develop the concept for hybrid material structure focal project and initiate tasks to develop necessary technologies • Complete a demonstration that integrates all of the Carbon fiber based research tasks to demonstrate technical and economic viability. • Complete the hybrid material structure focal project and tasks to develop necessary technologies.	42 months Barriers A, C, D

8	Phase 3 • Demonstrate integration of process modeling, property prediction modeling, and durability prediction modeling with crash energy management design models capable of optimizing composite vehicle structures. • Demonstrate production-ready molding and forming technologies in a full-scale demonstration based on carbon fiber composites • Develop and validate energy-absorption subsystem models and integrate those models into a vehicle structure • Validate vehicle-level models in crash tests • Integrate composite demonstration project technology into structural applications in production vehicles. • Integrate all materials projects technology developed into structural application in production vehicles including both metals and composites	36 months Barriers A, C, D

Table 3.4-5*. Tasks for Automotive Propulsion Materials*

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, D, G
	Manufacturability/durability research Phase 2 • Develop advanced, yet cost effective materials for HCCI engine components utilizing a computational design approach.	36 months Barriers A, C, G
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 • Optimize the design of power electronics that utilize SiC high-temperature wide bandgap materials in place of Si.	48 months Barriers C, G

Table 3.4-6 *Tasks for Heavy Vehicle Propulsion Materials*

Task	Title	Duration & Barriers
	Improved Materials for Fuel Systems	
1	Scuff and Wear-Resistant Materials • Develop advanced wear and scuff-resistant materials for applications in heavy-duty diesel fuel injection systems	36 months Barriers A, D, G
2	Advanced Manufacturing Technology for Fuel Injector Tips • Develop the manufacturing technology to support reliable and cost-effective drilling of ultra-fine, well-defined holes in fuel injector tips.	48 months Barriers A, D, G
3	Materials for High-Speed Fuel Injector Actuators • Evaluate new actuator technologies, characterize materials requirements, and develop materials and processing for advanced actuators for better fuel injection control.	48 months Barriers A, C, D, G
	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 • Characterize crystal structure, morphology, phase distribution, particle size, and surface species of catalytically active materials using X-ray diffraction, Raman spectroscopy. Materials to come from all stages of catalyst's lifecycle: raw materials, as-calcined, sulfated, regenerated, etc. • 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 • 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 Barrier G
5	Characterization of Diesel Particulate Filter Durability and Life • Characterize the microstructure and strength of DPFs when new and at various stages of simulated and actual life. • Develop and confirm testing and computational methodology to predict the useful lifetime of a particulate filter • Develop nondestructive evaluation techniques to allow the examination of DPFs at normal truck service intervals and predict the remaining useful DPF life	48 months Barriers C, G
6	Sensor Development • Develop materials for simple, effective, and low-cost sensors to support diesel engine exhaust aftertreatment technologies.	48 months Barriers A, G
	Improved Materials for Air Handling, and Thermal Control	
7	Advanced Materials for Heavy Duty Diesel Air Handling Systems • Develop cost effective, durable, and low-inertia materials to support the air handling requirements of heavy duty diesel engines	60 months Barriers A, B, C, D
8	Advanced Materials for Thermal Control • Develop advanced materials to enable the control of inlet and exhaust gas temperatures, critical component temperatures, and energy loss to the engine coolant.	84 months Barriers A, C, G

	Improved Materials for Structural Components	
9	High Strength Structural Components • Develop high-strength, fatigue and corrosion resistant alloys for structural components in advanced heavy-duty diesel engines. • Develop lightweight substitutes for heavy-duty engine blocks and cylinder heads.	60 months Barriers C, G
	Improved Materials for Hot-Section Components	
10	Light-weight Valve Train components • Develop light-weight components to facilitate variable valve timing, camless engine design, and to withstand high-temperature, corrosive environments.	96 months Barriers A, D, F, G
11	Advanced Materials for Diesel Engine Combustion Chamber • Evaluate the Tribological characteristics of hot-section components in order to reduce frictional losses • Develop cost-effective manufacturing processes for high-temperature, corrosion-resistant materials such as superalloys, intermetallics, and ceramics.	96 months Barriers A, C, D, G
	Characterization of Physical and Mechanical Properties	
12	Mechanical Behavior and Life Prediction of Diesel Engine Components • Evaluate the physical and mechanical properties of candidate materials for use in heavy-duty engines. • Develop new ASTM, ISO, and SAE testing standards for advanced materials.	96 months Barrier C
	Emerging Technologies	
13	Evaluation of Emerging Technologies • Evaluate promising new technologies for feasibility and determine potential for inclusion in future activity. • Evaluate impact of new fuel formulations and advanced combustion regimes on component materials requirements.	96 months Barriers A, B, C, G

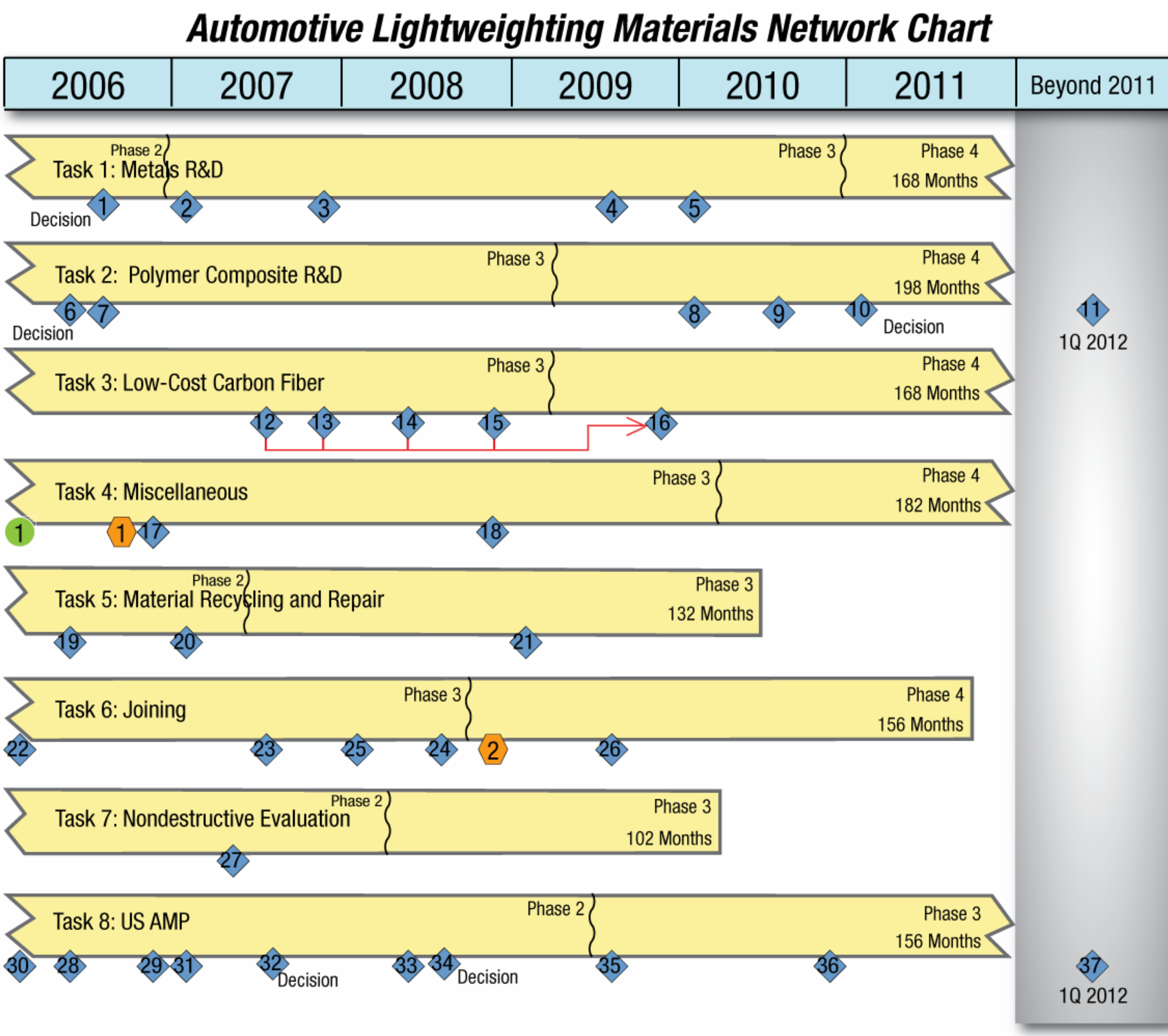
Table 3.4-7. *Tasks for High Temperature Materials Laboratory*

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 Barriers C, F, G
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 Barrier G
3	***Materials for Hydrogen Generation, Storage, and Utilization***	72 months

	• 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	Barrier G (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

3.4.11 Milestones & Decision Points

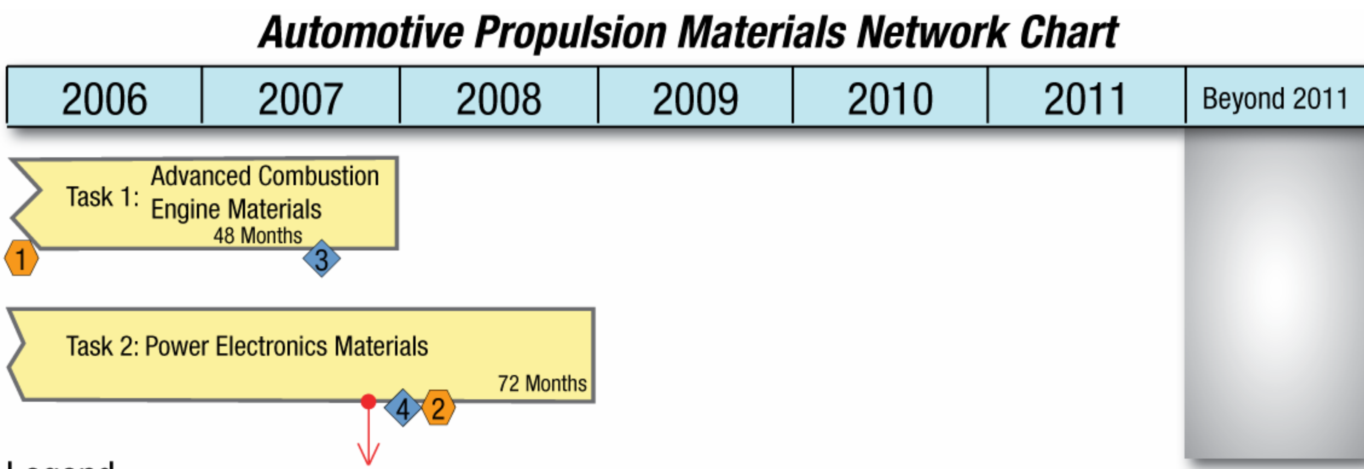
Milestones for the activities within the Materials Technologies subprogram are provided in the following charts.



Legend

Milestone	Milestone	Milestone
1. **Decision.** Complete initial evaluation of nano-reinforced Metal Matrix Composites for automotive applications. Decision point for moving from exploratory research to applied research leading to Milestone 5 2. Complete development of models for prediction of the response of metallic components to deformation during forming and use 3. Develop warm-forming technologies for magnesium sheet 4. Complete evaluation of low-cost magnesium sheet produced by twin-roll casting techniques 5. Complete component demonstration of high ductility nano-reinforced aluminum metal matrix composites for suspension application 6. **Decision.** Define critical technical needs for developing predictive models for thermoplastic composites. Decision point for tasking leading to Milestone 9 7. Complete installation and checkout of the P4C for making Carbon Fiber Preforms 8. Complete development of and demonstrate a low cost carbon fiber structural sheet molding compound 9. Complete development of predictive models for thermoplastics 10. **Decision.** Demonstrate a modified natural fiber reinforced composite with moisture induced strength reduction of no more than 8% 11. Demonstrate hybrid material preforming using carbon and glass fibers simultaneously integrated into a preform 12. Demonstrate satisfactory material properties from lignin based precursors produced as a large tow 13. Demonstrate low cost, non-thermal methods for optomizing carbon fiber precursors 14. Complete installation and check-out of the advanced technology carbon fiber production unit and user's center 15. Demonstrate low-cost, non-thermal methods for stabilizing carbon fiber precursors 16. Validate, via economic analysis, low cost carbon fiber production methods and materials that will yield fiber that costs less than $3.50 per pound	17. Develop an understanding of the effect of strain-rate-dependent materials on crash energy absorption capabilities 18. Demonstrate test methods to obtain material parameters that were previously not measurable 19. Complete evaluations of technologies for bulk separation of shredder residue, including electrostatic separation, hydrodynamic floatation, and gravity table separation 20. Demonstrate technology for the removal of substances of concern from recycled automotive materials 21. Complete comprehensive report detailing technology and infrastructure requirements for the recycle of advanced lightweight components and systems for advanced vehicular designs (e.g., hybrids and hydrogen fueled vehicles) 22. Complete evaluation of energy absorption capabilities of prototype bonded and mechanically fastened structures 23. Demonstrate friction stir spot welding techniques for advanced high strength steels 24. Demonstrate welding technologies for application to joining of different product forms of aluminum (e.g., hydroformed tubes to castings) 25. Complete development of predictive models for dimensional control of welded assemblies 26. Demonstrate effective and reliable thermoplastic welding techniques for joining 2 thermoplastic composite parts 27. Demonstrate NDE techniques for real time inspection and control of adhesive bonds and resistance spot welds in aluminum structures at production rates 28. Develop corrosion/wear coatings for completed magnesium components 29. Develop models for processing of powder metals and prediction of performance of PM components 30. Complete Focal project 3 full scale production demonstration of the "B" pillar assembly 31. Complete development of a crash energy management data base to include all work performed under this program	32. **Decision.** Complete designs for hybrid materials focal project prototype structure and define critical path forward. Decision point before proceeding to Milestone 34 33. Validate vehicle-level models for energy absorption in crash tests 34. **Decision.** Complete first prototype of hybrid materials focal point structure and identify manufacturing processes. Gate prior to starting work on Milestone 35 35. Complete hybrid material focal project 36. 1st demonstration of high volume hybrid materials technology on a production vehicle 37. Demonstrate integrated modeling and structural analysis of injection molded thermoplastic automotive structure, including crash energy modeling **Technology Program Output** 1. Validated technologies for production of Carbon Fiber at a cost of $3/lb available to industry 2. Hybrid body-in-white weight and performance data available to Vehicle Systems Analysis

Figure 3.4-2. Network Chart for Automotive Lightweighting Materials



Legend

Milestone

1. In collaboration with industrial partners, demonstrate advanced emissions treatment systems to comply with regulations for PM and NO_X
2. Demonstrate the advantages of using high conductivity carbon foam in advanced cooling technologies such as spray cooling and evaporative cooling
3. Provide emission control systems to diesel engine manufacturers for performance, reliability, and durability testing
4. Demonstrate advanced power electronics cooling technology that is lighter, lower cost and can accommodate the increased cooling needs of higher power density electronics

Milestones

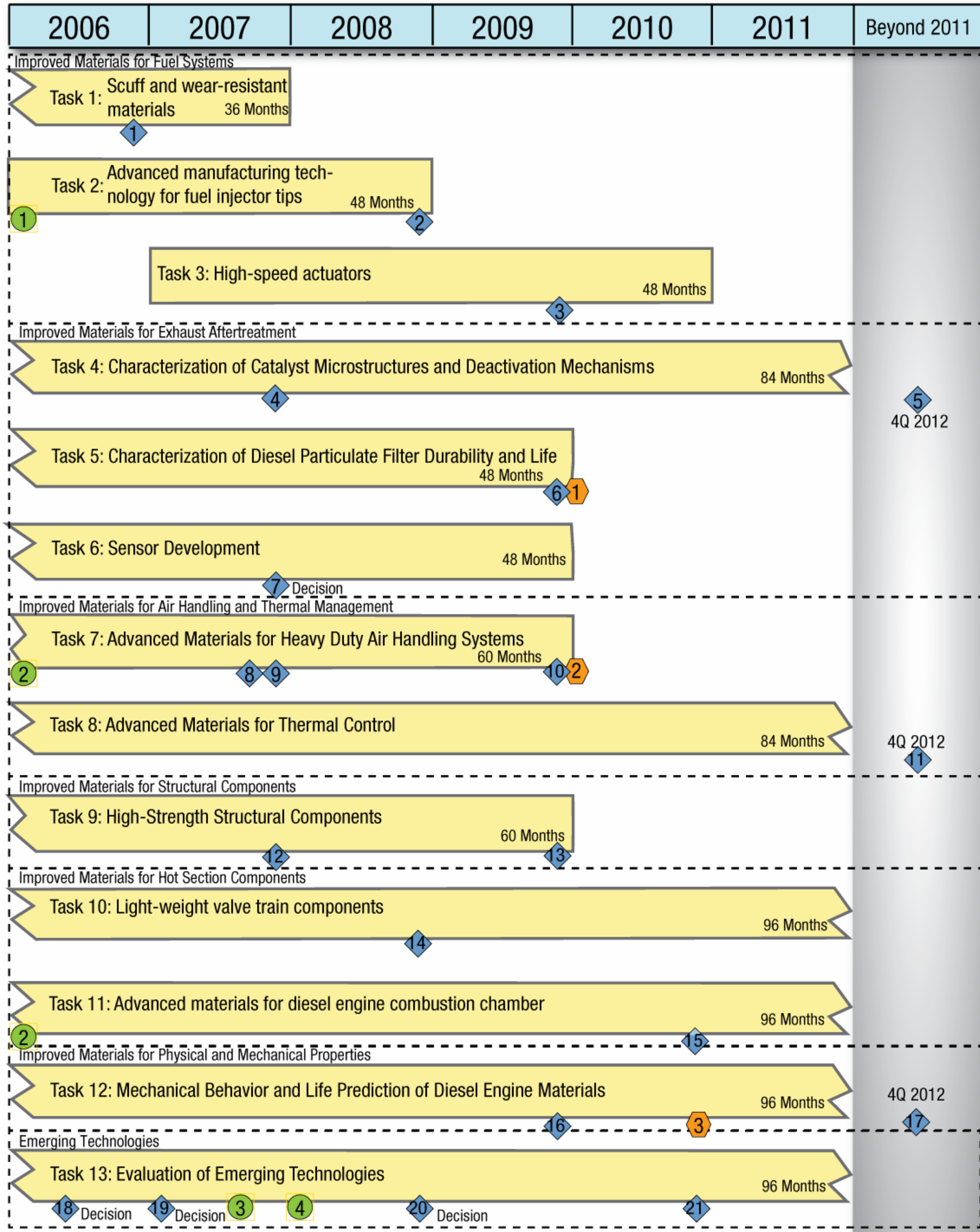
5. Demonstrate that coated fuel injectors with smaller orifices improve fuel distribution, increase engine efficiency and reduce emissions
6. In collaboration with industry, introduce advanced material for the most critical component identified for the successful use of HCCI engine concept
7. Develop a general model using finite element analysis that developers and manufacturers can utilize to design and fabricate SiC-based devices with reliability that is comparable to conventional Si-based devices
8. Demonstrate improved wear and increased reliability of advanced materials for use in hydrogen internal combustion engines

Technology Program Output

1. Validated emission control devices available to industry, Vehicle Systems, and Advanced Combustion Engine R&D
2. Validated Power Electronics cooling technology available to industry and Vehicle Systems

Figure 3.4-3. Network Chart for Automotive Propulsion Materials

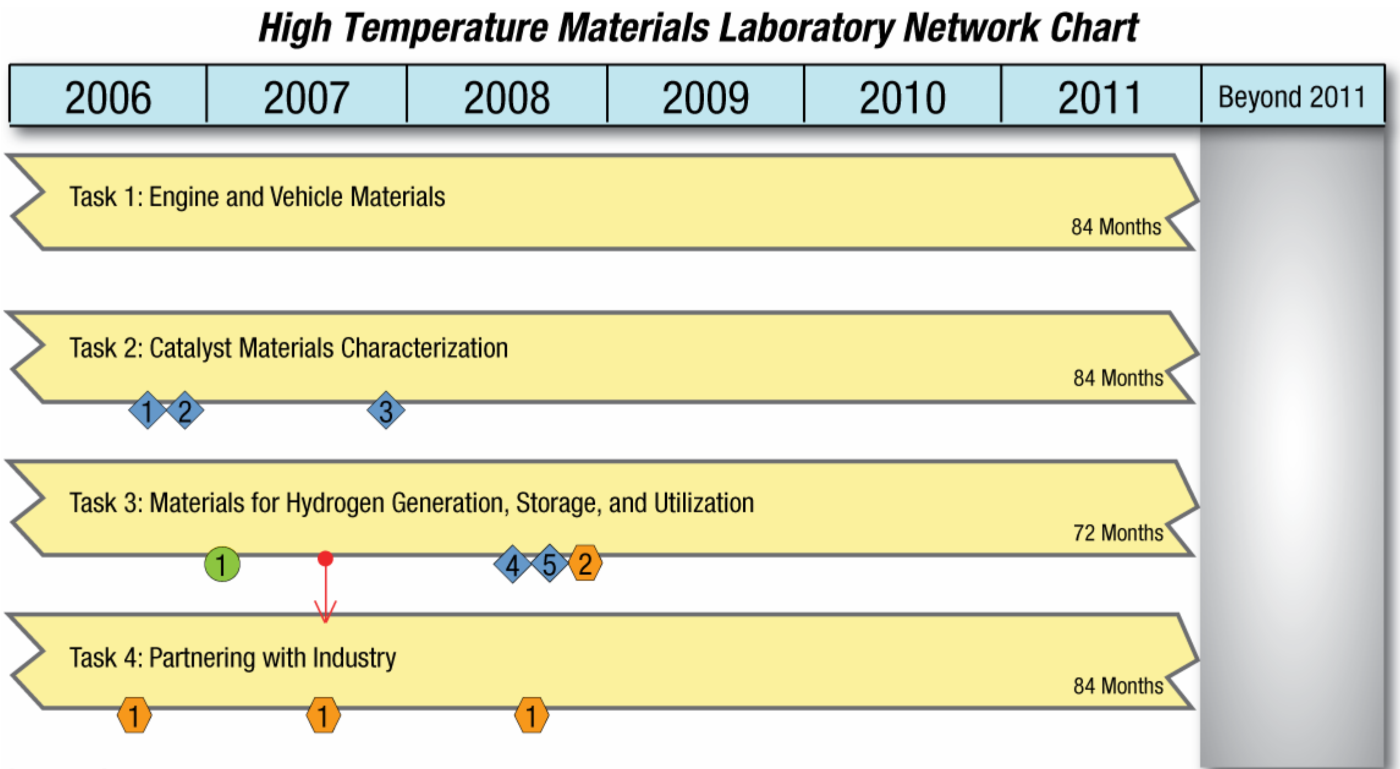
Heavy Vehicle Propulsion Materials Network Chart



Legend

Milestone	Milestone	Technology Program Output
1. Commercial introduction of Ni3Al-TiC component 2. Develop production-viable drilling of well-defined, ultra-fine holes in fuel injector tips 3. Develop and validate durable, reliable, and cost-effective materials and stack/ electrode manufacturing processes for high-speed, high-precision fuel injectors 4. Complete comprehensive study of durability and performance of catalytic systems for NOx reduction. Go/no-go 5. Complete evaluation of the nanoscience foundation (theory, processing, characterization) of catalyst performance and durability for heavy-duty applications 6. Complete evaluation of durability and expected life of particulate filter substrates **7. Decision.** Complete materials development for NOx sensors 8. Develop high-temperature aluminum alloys for high-efficiency, high-durability air-handling components in EGR environment 9. Go/no-go. Develop low-inertia titanium aluminide turbocharger wheel and associated joining technology for the joint with the shaf 10. Complete development of materials to enable advanced turbocharger for low-temperature combustion diesel engine 11. Complete development of advanced materials to facilitate reduction of thermal energy to the engine coolant by 50% 12. Complete development of austenitic stainless steels for high-temperature and EGR-tolerant diesel engine exhaust manifolds	13. Complete evaluation of light-weight materials for diesel engine blocks and cylinder heads 14. Go/no-go. Complete development of joining technology for joining of dissimilar valve head – valve shaft pairs 15. Complete evaluation/development of materials for cylinder liners, pistons, piston rings, and valve seats for low-temperature combustion diesel engines 16. Complete evaluation of creep and low-cycle fatigue of advanced, high-temperature aluminum alloys 17. Complete evaluation of mechanical behavior of emerging materials for application in advanced, high-efficiency diesel engines 18. **Decision.** Complete feasibility study of use of mechanical energy to reduce the time and/or temperature required to stress relieve engine components 19. **Decision.** Complete feasibility study of the consolidation of nanocrystalline machining chips to make ultra-strong engine components by incorporation of mechanical energy to reduce sintering temperature 20. **Decision.** Develop processing parameters to fabricate ultra-strong, nanocrystalline engine components from machining chips via the use of mechanical energy to reduce the sintering temperature and avoid grain growth. Complete preliminary mechanical property characterization 21. Fabricate prototype ultra strong, fatigue-resistant diesel engine components having nanocrystalline structure and evaluate performance in rig and engine tests	1. Validated catalyst and particulate filter materials to enable fuel efficiency and emissions requirements to Advanced Combustion Engine R&D 2. Commercially available, cost-effective high-temperature stainless steels to Heavy Truck Engine R&D 3. 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 3. Materials requirements for new combustion regimes and emission control devices from Advanced Combustion Engines 4. Materials requirements for advanced fuel formulations from Fuels Technologies

Figure 3.4-4. Network Chart for Heavy Vehicle Propulsion Materials



Legend

Milestone	Technology Program Output	Supporting Input
1. Utilize ACEM in the study of an experimental NOX trap material, showing imaging capabilities not possible to achieve using any present-day microscopy capability at ORNL 2. Launch commissioning of VULCAN 3. Study 2 experimental diesel NOX-reduction materials using a combination of HTML's ex situ catalyst reactor for TEM specimens, and the imaging and spectroscopy of ACEM 4. Demonstrate utilization of SNS (VULCAN) for time-resolved in-situ characterization of hydriding-dehydriding of hydrogen storage materials 5. Correlate atomic-level structure of a hydrogen-storage material, determined by ACEM, with structural phenomena revealed using neutron beams, to elucidate storage mechanisms	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	1. Candidate hydrogen storage materials from HFCIT

Figure 3.2-5. Network Chart for the High Temperature Materials Laboratory

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