# FreedomCAR and Fuel Partnership

## *Materials Technology Roadmap*

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## The Role of Materials in the FreedomCAR and Fuel Partnership (FreedomCAR)

Materials have two major roles in FreedomCAR:

1. As enablers for providing lightweight vehicle structures thereby improving fuel economy and reducing demands on the vehicle powertrain and ancillary systems (e.g., braking).

2. As enablers for specific vehicle applications predicated on use of hydrogen as an energy conversion medium, including fuel cells, hydrogen storage, electric drives and hydrogen-fueled internal combustion engines.

The 2010 Technology-Specific Research Goals for "Materials" as stated in the FreedomCAR and Fuel Partnership Plan are:

"Material and manufacturing technologies for high-volume production vehicles which enable/support the simultaneous attainment of:

- 50% reduction in the weight of the vehicle structure and subsystems
- affordability
- increased use of recyclable/renewable materials"

These goals were chosen so as to be deliberately unspecific with regard to specific vehicle styles or comparator weights, in light of the transitional nature of the marketplace.

Reducing both the cost of primary material production and manufacture of componentry using lightweight materials (or materials that enable mass reduction, i.e., so-called “lightweighting” materials) is critical to achieving mass reduction and affordability targets. This is because lightweight materials (e.g., aluminum, magnesium, metal-matrix composites, carbon-fiber composites) are typically more costly per unit of volume when compared to steel or cast iron as baseline materials. The impact of a specific material on total vehicle cost also is reflected in the associated manufacturing systems, which include such operations as primary and secondary forming, joining, finishing and assembly. Thus, while a particular material may exhibit a higher cost in its primary form, the overall cost of producing a component for incorporation in the vehicle may achieve certain economies due to simplifications in design and/or manufacturing.

Lightweight materials are, in some instances, less recyclable than incumbent materials. Thus, recycling technologies for these materials become more important as their use increases. Recycling of vehicle materials takes two principal forms: 1.) prompt recycling within the manufacturing process (e.g., remelting of runners and sprues for metal casting) and 2.) vehicle dismantling and material recycling at end-of-life (EOL). Improvements in prompt recycling are economically critical for materials such as magnesium, where up to 50% of the material handled in processes such as die casting may be consumed for runners, biscuits and sprues. Current EOL vehicle recycling is typically quite efficient on a weight basis for today's vehicles (often in excess of 85% of vehicle weight), and is aided by a profitable network of dismantlers, shredders and materials processors. Polymeric materials (e.g., foams), mineral oxides and glazings are among the greatest challenges for recyclers, and in some instances it is presently preferred to incinerate a polymer for its fuel content as opposed to separation and recycling in its original form (e.g., thermoplastics). European directives are currently placing a limit on the amount of EOL materials which can be burned as fuel, and a similar limitation could eventually occur in the United States. For highly-valued metals, including noble metals (e.g., platinum, palladium, rhodium) and certain metal alloys (e.g., sheet aluminum, stainless steel), extraction and dismantling technologies based on separation technologies are cost-effective and may be significant in total life-cycle cost of a given material system (e.g., wrought aluminum), thereby contributing to the affordability of using the material.

In addition to applications of lightweight materials for vehicle and component structures, it is also anticipated that materials technologies will play a significant role in broader FreedomCAR vehicle technologies with regard to such features as hydrogen storage, energy conversion devices, electrical and electronic systems, and improved reliability. Dialogue between the Materials Technical Team (MTT) and other FreedomCAR and Fuel Technical Teams is an important aspect of providing a pathway to the appropriate materials expertise within the community of participants, as well as a first step in developing aligned or joint programs where beneficial.

## Organization and Processes

### A. Organization

Innovative developments in materials technologies for FreedomCAR require cooperation among the various USCAR partner organizations, their industrial and university suppliers and the Office of FreedomCAR and Vehicle Technologies (OFCVT) of the U.S. Department of Energy. The Department of Energy's Office of FreedomCAR and Vehicle Technologies conducts research in the area of automotive lightweight materials that supports the goals of FreedomCAR primarily through the Automotive Lightweighting Materials (ALM) technology development area or 'thrust'. (The FreedomCAR Automotive Propulsion Materials thrust has also provided funding to support the goals of certain FreedomCAR materials efforts but is not reviewed through the FreedomCAR Materials Technical Team.)

The United States Automotive Materials Partnership (USAMP) is a consortium of original equipment manufacturers (OEMs) consisting of Ford Motor Company, General Motors Corporation and DaimlerChrysler Corporation focused on pre-competitive, collaborative materials research, operating under the umbrella of the United States Council for Automotive Research (USCAR). USAMP participates in materials research supporting the goals of the FreedomCAR and Fuel Partnership through a Cooperative Agreement with the U.S. Department of Energy, in collaboration with the ALM thrust. This agreement provides for DOE cost-sharing with the various USAMP project partners up to an annual budgeted limit.

The USAMP subsidiary organizations, operating under USCAR include: the Automotive Composites Consortium (ACC) and the Automotive Metals Division (AMD). Additionally, the Cooperative Agreement provides for projects organized under the Auto-Steel Partnership (A/SP), an organization whose members include the OEMs and certain North American steel suppliers. The Steering Committee of the USAMP oversees the budgeting requests for projects funded under the Cooperative Agreement. The DOE's management of the Cooperative Agreement is conducted by the National Energy Technology Laboratory (NETL), located in Morgantown, West Virginia.

The Vehicle Recycling Partnership, like USAMP, is a USCAR consortium of OEMs. It conducts its research primarily through the mechanism of a Cooperative Research and Development Agreement (CRADA) with Argonne National Laboratories and the American Plastics Council. DOE financial support of this CRADA is also through DOE's ALM thrust.

Other organizations with aligned interests in automotive materials that have participated in DOE's ALM thrust include: The Aluminum Association, The Society for the Advancement of Material and Process Engineering (SAMPE), The American Iron and Steel Institute (AISI), The International Magnesium Association, The International Titanium Association and the Auto Parts Rebuilders Association.

The Materials Technical Team (MTT) is one of eleven FreedomCAR "tech teams" and is comprised of OEM company representatives (two for each company) and representatives of DOE's Oak Ridge National Laboratory and Pacific Northwest National Laboratory (one representative each), as well as the DOE ALM manager. The mission of the MTT is to develop R&D plans and roadmaps, review research results, and evaluate the technical progress toward meeting the Partnership's materials related research goals. Decisions on disposition of Federal funds supporting the goals of the FreedomCAR and Fuel Partnership are the responsibility of the DOE ALM Program Manager. The MTT and the USAMP Steering Committee share a common philosophy with respect to lightweight automotive materials R&D and both provide suggestions on the overall strategic thrust of the ALM portfolio.

**B. Processes**

Since the inception of the FreedomCAR Partnership in 2002 and its expansion to the FreedomCAR and Fuel Partnership in 2003, the Materials Technical Team has been transitioning its focus from the prior Partnership for a New Generation of Vehicles (PNGV) to the new initiative. While the general flavor of the technology-specific goals is similar (weight reduction, affordability), there are new challenges associated with recycling of advanced materials and design of vehicle systems predicated on the use of hydrogen as a fuel. Furthermore, the work carries over a number of materials lightweighting projects that had begun under PNGV. While the "processes" for the Materials Technical Team in the context of the FreedomCAR and Fuel Partnership will continue to evolve, the following elements are believed to be essential:

1.) **Review Cycle** – The MTT aims to conduct a review cycle intended to coincide with the Federal fiscal year calendar, such that suggestions are provided to DOE in time for DOE project decisions (new starts, terminations, continuations) to be effected prior to Oct. 1 of each year.

2.) **Strategic Reviews** – During 2004, the MTT instituted a series of strategic reviews and discussions in nine specific subject areas of primary interest to the team, namely:

advanced high-strength steels (AHSS)
aluminum
carbon-fiber, polymer composites
emerging materials
glazings
magnesium
metal matrix composites (MMCs)
recycling
titanium

These reviews and ensuing discussions by the team were used to arrive at a specific strategic focus and targeted needs for each material or subject area. The statements of strategy for each subject are summarized in Figures 2-10.

3.) **Project Evaluation and Tracking** – It has been recognized by the MTT that an improved procedure for ongoing project evaluation and tracking is in order. Team representatives are working with USCAR management to identify and implement such a tool as soon as possible.

## FreedomCAR Materials R&D Approach

### A. Technology Staging Process

Prior representations of the materials efforts for USAMP and for the FreedomCAR and Fuel Partnership have employed a "cone" model to depict the vision that present-day research on a large number of high-risk, futuristic concepts, typically results in a small number of alternatives which eventually become feasible as time progresses and knowledge improves. Furthermore, unexpected breakthroughs and "disruptive" technologies drive future states that are not always envisioned at a particular point in time.

Figure 1 portrays some of the elements of the "cone" model and project staging envisioned for FreedomCAR materials efforts. In this representation, the project portfolio is seen as having a relatively larger number of projects aimed at concept feasibility, and fewer, but larger projects at the technical and demonstration feasibility levels. Conceptually, projects are "staged" in the sense of passing through technical and budgetary gateways that are defined for the success of the proposed technology. New projects, however, can be initiated in any appropriate stage if and when an acceptable idea is submitted.

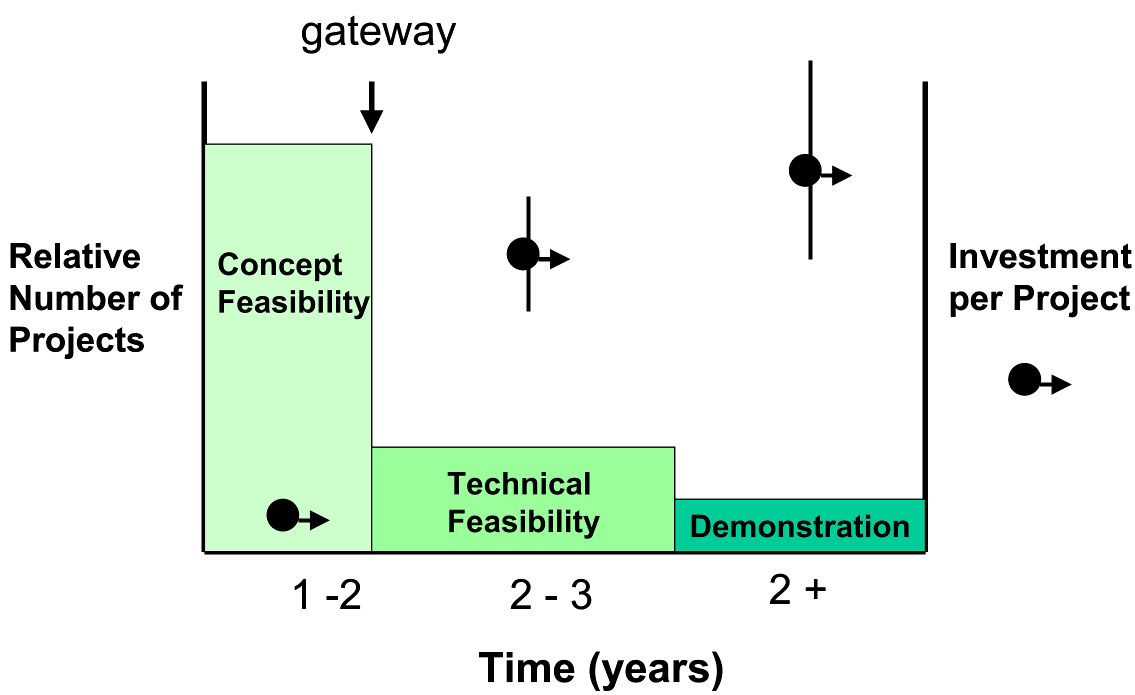


Figure 1. Representation of a vision for research staging, investment and timing for FreedomCAR materials projects.

**Concept Feasibility** projects are aimed at evaluating a specific idea to solve a problem and/or to create something new. These projects are usually exploratory in nature, low in monetary requirements ($100K - $200K) and short in duration (1-2 years). Such projects should provide a yes/no answer to the value of the concept or invention. Concept feasibility projects are expected to have a detailed research plan, budget and timing. These projects can be terminated before proceeding to the technical feasibility stage if there is a lack of technical progress, or if the preliminary business case turns out to be unfavorable. Successful concept feasibility projects can be developed into technical feasibility projects having a greater level of financial support.

**Technical Feasibility** projects continue research and development for those concepts with proven merit or potential. These projects should identify the key barriers to implementing the technology and focus on overcoming them. Technology feasibility projects should have well defined OEM/Industry supplier participation and pull. They are usually larger, longer-term projects than the concept feasibility projects with typical total research investment in the 1 to 2 million dollar range and length of 2-3 years in duration. Technical feasibility projects can also be terminated before proceeding to demonstration feasibility if there is a failure to overcome the key barriers to implementing the technology or if the cost or business case does not develop as favorably as initially assessed.

Technical feasibility projects that need larger scale validation (e.g., a pilot plant) may evolve into **Demonstration Feasibility** projects. Not all successful technical feasibility projects will need a demonstration or validation program. These projects are expected to be few in number, much larger in scale and may involve component or system fabrication and testing. Financial and technical leverage from the OEMs and supply base are required for these projects.

## B. Lightweighting Materials Research:

Background.

The materials effort under the predecessor program to FreedomCAR and Fuel Partnership (i.e., PNGV) was aimed at weight reduction of the vehicle structure and component systems as a principal contribution to the achievement of the fuel economy goal (i.e., up to 80 mpg) that was a target for that program. Although FreedomCAR objectives are not framed in terms of specific fuel economy, weight reduction of the vehicle still remains a primary consideration. This is because hydrogen power systems, either employing fuel cells or internal combustion engines, are expected to be heavier and more costly than the present-day conventional propulsion systems they would replace. Lighter vehicles require smaller, less costly powertrains and also consume less fuel while achieving equal performance.

The FreedomCAR target for weight reduction of the vehicle and its subsystems is 50%. The target was intentionally unspecific with regard to any particular vehicle style or point in time. Reduction of vehicle weight has been accomplished in the past through a combination of design optimization, downsizing and the use of lower-density materials with suitable mechanical properties, i.e., materials with higher strength to weight and/or higher stiffness to weight ratios.

Strategic Overview.

i.) Materials Cost

Since affordability is a principal goal for the MTT, it is important to appreciate the nature of the materials marketplace in the establishment of the "cost" for any material. While the MTT focuses its research on the costs of extraction and processing lightweight materials, the laws of supply and demand also influence the ultimate cost of a material to an OEM. A primary materials producer, for example, may be inclined to capture advantages in the marketplace instead of passing such efficiencies on to the automobile manufacturer. The OEM does, however, gain from more efficient use of advanced materials and lower-cost manufacturing processes that are under direct control.

ii.) Vehicle Design.

Whereas PNGV ultimately dealt with specific approaches, and consequently actual vehicle designs by each OEM toward achievement of the program objectives, FreedomCAR operates from a much broader framework. Advances toward the program objectives tend therefore to be more general in nature and represent a "least common denominator" among the participants when it comes to choosing research directions.

The use of a variety of lightweight materials in automotive applications has been the subject of extensive research and development over many years. Current automobiles contain larger quantities of such materials as high strength, low-alloy steels, aluminum, plastic, polymer composites and magnesium, than did their counterparts in the 1970s. However, to achieve significant vehicle weight reduction, it will be necessary to apply these and other, more novel "lightweighting" materials and methods of manufacture in a much wider range of applications. All components of the vehicle must be considered for the potential application of weight-reducing materials and design optimization, as well as synergistic effects on powertrain and chassis accruing from reductions in weight of the body structure. In deciding what materials to emphasize for research and development in the FreedomCAR effort, the weight reduction potential and the challenges to the use of each lightweight material have been considered.

The leading candidates for application in body structure include advanced high strength steels (AHSS), aluminum, magnesium, polymer composites, and combinations of these materials. For chassis and powertrain structural applications, the primary material options include aluminum, magnesium, polymer composites, AHSS, MMCs and titanium. Additionally, specialized materials and approaches must be considered for certain applications where few alternatives exist (e.g., glazings).

iii.) Lightweight Materials Portfolio.

The following sections have been organized to include nine tables which portray the broad strategic framework for the principal materials and technologies (e.g., recycling) as agreed and understood by the Materials Technical Team (Figures 2 – 10). The strategic framework for each topic has been developed through the ongoing series of strategic discussions by the team members and selected specialists. The relevant USAMP subteams have participated in these discussions. The Research Objectives contain a strategic frame, which defines the opportunities for each material as well as mid-term (3-5 years) and long-term (5-10 years) goals for that material or technology. The research activities under the direction of USAMP/MTT are chosen to support the achievement of the mid-term and long-term goals for each of these materials. Furthermore, each strategy outline suggests research activities, which are believed by the MTT to be required for advancing any particular material or technology toward its goals.

**Advanced High Strength Steels.** Considerable work has been done by the international steel industry in the development of advanced high strength steels (AHSS) for automotive applications, however, significant work still remains to be done. The ULSAB-AVC (Ultralight Steel Auto Body – Advanced Vehicle Concepts) project highlighted the potential for extensive use of AHSS in vehicle body. AHSS differ from conventional mild steels because they are manufactured using a combination of alloy compositions and processing methods to achieve high strength without significantly compromising formability. What remains is the difficult task of developing the manufacturing technologies to make the production and use of these new materials possible and economically attractive on a high volume scale. Although OEMs and suppliers are working on some of these challenges, there are still opportunities for collaborative projects.

**Materials**

Advanced High-Strength Steels

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| High strength steel developed to replace conventional steel parts will achieve a mass reduction of 30% on a component by component basis. Up to 15% weight savings can be achieved for the total body structure. Higher weight reduction requires significant changes in vehicle body architecture which deviate from the current proven methods of vehicle body construction. Today's relative cost per part vs. conventional steel is 1.0-1.5. | Long-term goal (5-10+ years)<br>**Enable the use of advanced steels to create components and structures with 20-35% wt reduction achieving up to 15% lighter vehicle body structures and cost parity with incumbent materials.**<br>Intermediate goals (3-5 yrs.)<br>**Enable the use of advanced steels to create components and structures with 15-25% wt reduction and systems cost of <$0.50/kg ($0.25/lb) saved, without significant changes to currently proven manufacturing processes.**<br>1.Achieve sheet material cost reduction to further reduce the cost of steel components and structures.<br>2.Develop an improved understanding of the automotive manufacturability and performance of advanced high strength steel components.<br>3.Develop improved alloys that have higher strength with better formability, improved structural and crash performance, and with little or no manufacturing issues | Current Projects<br>ASP 050 HSS Stamping<br>ASP 060 Hydroforming<br>ASP 070 HSS Joining Technologies<br>ASP 090 Lightweight Closures<br>ASP 160 Sheet Steel Fatigue Characteristics<br>ASP 190 Strain Rate Characterization<br>ASP 210 HSS Tailor Welded Blanks<br>ASP 230 Tribology<br>ASP 240 Next Generation Safety Cage<br>AMD 302 Long Life Electrodes<br>AMD 301 Flexible Binder Control System for Robust Stamping<br>AMD 408 Die Face Engineering<br>Thermo-Mechanical Behavior of TRIP steels<br>Topics Requiring Further Research<br>-Material Naming Conventions for HSS and AHSS<br>-Tool Wear and Press Load Issues<br>-Friction Stir Spot Welding of AHSS |

**Technology Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of: ***1.) 50% reduction in the weight of vehicle structure and subsystems*, *2.) affordability and 3.) increased use of recyclable/renewable materials.***

Figure 2. Advanced High-Strength Steel Strategy

**Aluminum.** There are several types of vehicle body designs, which make use of aluminum in all of the major product forms: sheet, casting and extrusions. For chassis and powertrain, aluminum is most often applied in the form of castings, but extrusions, forging and stampings also are used in some applications. Aluminum components offer potential overall weight reduction of 40-60% when used to replace cast iron or steel, which achieves FreedomCAR goals. The biggest challenge faced in aluminum is in reducing raw material cost to achieve parity with incumbent materials at a systems level. Developments of high volume manufacturing techniques (sheet forming, joining, casting, machining, etc.) for aluminum components of all types based on conventional manufacturing processes is approaching maturity. However, additional development of new innovative tools and technologies to reduce manufacturing costs and raw material costs can further improve affordability.

FreedomCAR & Fuel Partnership **Materials**

## Aluminum

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Aluminum structures and components can be designed to replace steel and cast iron parts to achieve a mass reductions of 40-60%. Today's relative cost per part vs. traditional materials is 1.3-2.0. | Long-term goal (5-10+ years)<br>Enable the use of aluminum to create component and structures with 40-60% wt reduction and systems cost parity with incumbent materials.<br>Intermediate goals (3-5 yrs.)<br>Enable the use of aluminum to create component and structures with 40-60 % wt reduction and systems cost of <2$/kg (.9$/lb) saved.<br>• Achieve raw material cost reduction to enable overall system cost parity with incumbent materials.<br>• Develop improved alloys for better performance and/or manufacturing characteristics.<br>• Develop improved high volume manufacturing techniques for shaping (casting, forming, etc) and joining (welding, bonding, etc).<br>• Develop recycling to optimize scrap value. | Current Projects<br>•AMD 301 -Flexible Binder Control System<br>•AMD 302 -Long Life Electrodes for Al & Zn-Steel<br>•AMD 303 -NDE Tools for Laser Welded Al & Steel<br>•AMD 306 -Plasma Arc Welding for Al & Mg<br>•AMD 307 -Warm Forming of Aluminum<br>•AMD 309 -Aluminum Closure Corrosion Program<br>•AMD 311 Die Face Engineering<br>•NDE of Spot Welds (LBNL)<br>•Thread Forming Fasteners (PNNL)<br>•Forming Limits of Weld Metal in Al and HSS (PNNL)<br>Topics Requiring Further Research<br>• NDE of adhesive bonds and resistance spot welds<br>• Continuous cast alloys for exterior body panels<br>• Compatible low-cost sheet alloys for structures and exterior closure panels<br>• Innovative shaping technologies (impacts, high speed machining, low-cost high quality structural castings)<br>• Solid film forming lubricants<br>• Innovative joining technologies |

**Technology-Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of ***1.) 50% reduction in the weight of vehicle structure and subsystems, 2.) affordability, and 3.) increased use of recyclable/renewable materials.***

Figure 3. Aluminum Strategy.

**Carbon Fiber/Polymer Matrix Composites** - The roadmap considers polymer matrix composites for both components and BIW structures. The range of various polymer matrix materials and reinforcing fiber type and geometry results in an extremely broad range of possible composite compositions. Thus there is potential for a wide number of uses with a range of mass reductions over steel ranging from 25-30% (glass fiber systems) up to 60-70% (carbon fiber systems). The major key issues that need to be addressed with these materials are: cost reduction, supplier capability, high volume manufacturing, durability, crash energy management, joining, optimizing mass reduction and recycling.

Current efforts are focused in the development of large carbon fiber composite structures. One of the first tasks is to delineate the structural performance requirements and identify the best manufacturing technologies for producing the various components. The goal associated with this work is achieving a greater than a 60% mass reduction over a comparable steel body structure. A very large effort being carried out mainly through a combination of several DOE projects is aimed at reducing the cost of carbon fiber with a goal of $7-11/kg. The optimization of carbon fiber surface characteristics for compatibility with resins commonly used in the auto industry is also being undertaken.

**Materials**

Carbon Fiber/Polymer Matrix Composites

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
| --- | --- | --- |
| Carbon FRP developed to replace steel parts will achieve a mass reduction of 50-60%. Today's relative cost per part vs. steel is 2.0-10. | Long-term goal (5-10+ years)<br>**Enable the use of carbon FRP to create structures, relative to incumbent material, with 55-65% wt reduction and cost parity.**<br>-Low-cost carbon fiber<br>- Predictive modeling for crashworthiness<br>- Robust joining technology including optimum design and prediction of durability and failure<br>- Economical recycling<br><br>Intermediate goals (3-5 yrs.)<br>**Demonstrate technical feasibility of the manufacture of large structures from automotive grade carbon FRP so as to replace incumbent materials.**<br>-Develop durability-drive design guidelines<br>-Evaluate viable new molding processes<br>- Guide suppliers in developing carbon fiber materials to suit automotive requirements | Current Projects<br>•ACC040: Development and optimization of chopped carbon fiber preforms.<br>•ACC115: Optimize injection-compression processing based on characteristics properties of the preforms.<br>•Predictive modeling of structural adhesive joints<br>•ACC100: Developing models for prediction of crash energy management.<br>•ACC080: Focal Project 3 Design and manufacturing validation of a carbon fiber intensive BIW aimed at > 60% mass reduction.<br>•ACC205: Low Cost Test Methods for Advanced Automotive Composite Materials: Creep Compression Fixture<br><br>Topics Requiring Further Research<br>•Structural thermoplastic composites<br>•Class-A structural composites |

**Technology-Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of: ***1.) 50% reduction in the weight of vehicle structure and subsystems***, ***2.) affordability***, ***and 3.) increased use of recyclable/renewable materials.***

Figure 4. Carbon Fiber/Polymer Matrix Composites Strategy.

**Emerging Materials and Manufacturing Processes -** "Emerging materials" are seen as including novel structural materials and concepts not included in the primary categories of conventional structural materials for automotive manufacture. These materials would include (but are not limited to) structural foams and adhesives (both metal and polymeric), syntactic materials (incorporating space-filling, but lightweight particles), nano-composites, micro-tailored structures (so-called 'geodesic' materials), bio-mimetic materials, renewable-resource biomaterials, as well as new states of matter which might be identified for structural purposes. Similarly, emerging manufacturing processes might include methods of fabricating unique hybrid structures (e.g. metal/polymer composites) or altogether new means for extending the structural utility of existing materials (e.g. origami or folding processes for metals, selective structural strengthening by local heat treatments, ribbed or gusseted structural features, etc.). Novel manufacturing processes may also include special methods of joining dissimilar materials (e.g. adhesive bonding) or non-destructive test methods. It is expected that new initiatives may be introduced in this broad and growing field. The strategy in this case is to review each proposed topic on a case-by-case basis for assessment of its overall potential to meet program goals for weight reduction, affordability and recyclability.

Figure 5. Strategy for Emerging Materials and Manufacturing Processes.

FreedomCAR Fuel Partnership **Materials**

Emerging Materials and Manufacturing Processes

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Novel materials such as polymer and metal foams, syntactic materials, geodesic-tailored structures and adhesives offer the opportunity for improved structural integrity and weight savings in excess of what may be achieved from monolithic materials.<br><br>Manufacturing processes exploiting these new materials will be generally more complex than those currently in widespread use.<br><br>Each material and process will be considered on an individual basis for project development based on ability to meet overall project goals. | <u>Long-term goal</u> (5-10+ years)<br>Establish an engineering andmanu-facturing base for such advanced materials as identified below. (technical and demonstration feasibilities)<br><br><u>Intermediate goals</u> (3-5 yrs.)<br>Identify emerging materials and manufacturing systems with the potential to affect vehicle system weight reduction and cost. (concept feasibilities) | <u>Current Projects</u><br>(proposed) Low-cost nanocrystalline bulk forms from machining chips.<br><br><u>Topics Requiring Further Research</u><br>-bio-derived composite materials (fibers and polymer matrix)<br>-"prime reliant" design with metal and polymeric foams in structures<br>-structurally 'tailored' materials from merchant feedstocks<br>-internal strengthening of box-structure forms (hydroforms)<br>-Non Destructive Testing |

**Technology-Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of: ***1.) 50% reduction in the weight of vehicle structure and subsystems***, ***2.) affordability***, ***and 3.) increased use of recyclable/renewable materials.***

FreedomCAR Fuel Partnership **Materials**

## Glazings

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Glazing represents approx. 5% of the mass of a typical automobile. Lightweight glazing alternatives can result in a 50% weight reduction compared to conventional materials. Today's relative cost per part vs. conventional (laminated glass) material is 5x.<br><br>Glazing can also contribute to reducing vehicle energy consumption while improving passenger comfort by reducing cabin thermal load. | Long-term goal (5-10+ years)<br>**Use lightweight glazing materials for 50% Wt reduction with cost parity to today's materials and no compromise in safety performance (as defined under Intermediate Goals)**<br>Intermediate goals (3-5 yrs.)<br>**Use lightweight glazing materials for 30% wt. reduction with cost 2x vs. today's materials.**<br>A. Develop low cost lightweight glazing that will provide optical clarity and image quality, penetration resistance, and reduce potential for laceration and head injury<br>B Develop materials with comparable structural and durability performance<br>C. Develop modeling and simulation methods to predict noise and thermal transmission and structural performance<br>D. Develop materials or techniques to reduce noise transmission by 6 db<br>E. Develop materials to reduce cabin heat load by 95% IR light blocking | Current Projects<br>PNNL- Lightweight and High Performance Alternatives for Future Automotive Glazing Systems<br>- Evaluate thinner glass, glass/plastic laminates and injection molded interlayers<br>- Investigate design alternatives such as glazing curvature variations and laminates to reduce noise transmission<br><br>Topics Requiring Further Research<br>•Develop materials or techniques to reduce cabin heat load<br>• Develop materials, designs and processes for targeted db noise reduction<br>•Develop models to predict heat load, sound transmission, impact resistance.<br>• Use models to identify and drive continuous improvement efforts |

**Technology-Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of: ***1.) 50% reduction in the weight of vehicle structure and subsystems***, ***2.) affordability***, ***and 3.) increased use of recyclable/renewable materials.***

Figure 6. Strategy for Glazings.

**Magnesium -** Magnesium is a light metal, 30% less dense than aluminum, and is most commonly used in the form of die castings for powertrain and selected semi-structural components. As part of on-going research, key developments in magnesium are focused on: development of affordable creep resistant and corrosion resistant magnesium alloys, large magnesium cast structures, magnesium–based metal matrix composites (MMCs), and joining technology. Additional research needs include: improved machining; cost-effective, durable protective coatings; economical methods for production of magnesium sheet materials; forming technology; and methods for processing recycled magnesium. In addition, the atmospheres currently recommended for use in reducing oxidation and preventing fires while handling molten magnesium are based either on $SO_2$ or $SF_6$ and leave a great deal to be desired in terms of effective control, toxicity, and environmental impact.

FreedomCAR & Fuel Partnership **Materials**

Magnesium

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Magnesium components are envisioned to replace an equivalent volume of ferrous material with a mass reduction of 70-75%, and aluminum with a reduction of 25-35%.<br><br>Additional economic advantages may be realized for large magnesium die-castings (e.g. cross members, instrument panel supports, grill opening reinforcements, door inners, engine cradles) where larger numbers of individual steel stampings are replaced by a single die casting in magnesium.<br><br>The relative cost per part today for replacement of steel is 1.5-2.5X and 1.0-1.5 for replacement of aluminum | Long-term goal (5-10+ years)<br>Enable the use of Magnesium to create closures and large semi-structural and powertrain components with 60-75% wt reduction (Fe-based materials) or 20-30% (Al-based materials) and systems cost parity with incumbent materials.<br>Intermediate goals (3-5 yrs.)<br>Demonstrate technical feasibility for the creation of Magnesium closures and large semi-structural and powertrain components so as to replace incumbent materials approaching system cost of <$2/kg ($0.9/lb) saved.<br>A. Achieve feedstock cost reduction so as to enable overall cost parity with incumbent materials.<br>B. Develop improved high volume manufacturing techniques for shaping (casting, forming, etc.) and joining (welding, bonding, etc.).<br>C. Develop recycling to optimize scrap value.<br>D. Develop corrosion protection technology. | Current Projects<br>List of major activities<br>-AMD 111, 112 – Structural Cast Mg Development<br>-AMD 304 - Mg Powertrain Cast Components<br>-AMD 406 – Ultra-large Casting Development<br>-AMD 407 – Die Cast Net-shaped Hole Process Devlopment<br><br>Topics Requiring Further Research<br>- Low pressure casting<br>-Warm forming of Mg sheet<br>-Environmentally friendly replacements for SF6<br>-Recycling of prompt scrap, especially for creep resistant alloys<br>-Mg Metal Matrix Composites (MMCs)<br>-Thixomat cast Mg large body-on-frame structural components.<br>-Low-cost Mg sheet<br>-Fundamental studies of Mg (deformation, corrosion, creep behavior, impact, etc.)<br>-Wrought alloys with improved properties |

**Technology-Specific 2010 Goal for Materials:** To enable lightweight vehicle structures and systems, the goal is: Material and manufacturing technologies for high volume production vehicles which enable/support the simultaneous attainment of: ***1.) 50% reduction in the weight of vehicle structure and subsystems***, ***2.) affordability***, ***and 3.) increased use of recyclable/renewable materials.***

Figure 7. Strategy for Magnesium.

**Metal Matrix Composites** - Metal matrix composites are a relatively new family of materials, dating back only to the 1960s. As the name implies, the material consists of a metal reinforced with another material (typically in the form of ceramic fibers, whiskers or particles), which provides a composite material with properties that are enhanced relative to those of the original base metal. The improved properties include tensile and compressive properties (especially stiffness), creep stability, tailorable thermal expansion, and wear resistance. Thus, it is possible to increase the application of lightweight alloys in structural and powertrain applications due to their improved mechanical behavior and physical properties. The materials physical limitations are typically due to thermal fatigue, thermochemical compatibility, low ductility, and poor machinability. Aluminum reinforced with ceramic particles is a unique candidate for lightweight brake discs, calipers and other components. While metal matrix composite components, such as brakes, are in production on selected specialty cars, they are limited due to cost and performance capability. The major challenges are the costs of feedstock, the cost of combining the reinforcement with the matrix in production, and the cost of shaping / machining MMC components. Significant progress has been made in reducing the cost of the mixing process through the use of the modular mixing technique developed under the PNGV and FreedomCAR efforts. However, significant development is still needed in the areas of rapid, low cost near net shape forming and machining. Magnesium metal matrix composites could also offer further weight reduction, but require development of affordable processing and manufacturing methods. Major challenges include increasing the modulus 50% to be equivalent to aluminum, and improving magnesium's creep resistance without addition of expensive rare earth materials.

**Materials**

Metal Matrix Composites

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Increase the application of lightweight alloys in structural and powertrain applications by improving their mechanical behavior and physical properties through the integration of reinforcing fibers, whiskers or particles.<br><br>Develop MMCs to replace steel/cast iron parts such as brake discs, calipers and various chassis and powertrain components to achieve mass reductions of 50-60%. Today's relative cost per part vs. steel is 1.5-3+x. | Long-term goal (5-10+ years)<br>Use MMC to create structures with 60% wt reduction and cost parity vs. today's steel or CI<br><br>Intermediate goals (3-5 yrs.)<br>Use MMC to create structural components and with 50% wt reduction and relative cost per part of 2.0X<br>A. Develop and validate lower cost reinforcement materials.<br>B. Develop improved powder handling and compaction technologies.<br>C. Develop improved forming processes<br>D. Develop improved machining processes. | Current Projects<br>•PNNL Low-Cost Cast MMCs<br>•AMD 310 Low-cost PM Titanium Processing<br><br>Topics Requiring Further Research<br>•Examination of "nano"-reinforced and high volume fraction MMC<br>•Magnesium MMC with low cost alternative to rare earth strengthening for improved creep resistance<br>•Large scale development of in-situ processes<br>•Modeling of PM process<br>•Modeling of performance of PM components<br>•Low Cost Machining of MMC<br>•TBD Fuel Cell applications<br>•TBD Thermal applications |

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Figure 8. Strategy for Metal Matrix Composites.

**Recycling** – Automakers promote economic and environmental sustainability by routinely examining the life-cycle impacts of vehicle materials. To achieve greater fuel-efficiency and safety, today's cars incorporate an increasing share of innovative lightweight materials. While these materials greatly enhance efficiency during vehicle use, they can present special challenges to recycling. Research is needed to remove any recycling barriers, real or perceived, that might preclude the use of advanced lightweighting materials or systems in future vehicles. Research has been successfully completed on the development of processes for recycling of polymer matrix composites and aluminum alloys. Under a CRADA between Argonne National Laboratory, the Vehicle Recycling Partnership of USCAR and American Plastics Council, research is being conducted to enable the optimum recycling of all automotive materials from end-of-life vehicles. Mechanical recycling, or recovery of materials for re-use in automotive applications is just one technical approach being pursued. Other recycle technologies under study include energy recovery and the conversion of end-of-life vehicle materials and shredder residue to chemicals and fuel. Analyses of the recyclability of advanced vehicular designs, (e.g., hybrid and fuel cell) also are being conducted to identify recycling technology gaps.

Recycling — FreedomCAR & Fuel Partnership — ***Materials***

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Economic use of advanced lightweight materials for automotive construction will be enhanced by both prompt recycling of scrap materials during manufacture, as well as recycling of end-of-life vehicles incorporating such materials.<br><br>Cost structures for materials such as aluminum and magnesium are strongly impacted by availability and cost of usable alloy scrap and retention of critical alloy properties.<br><br>For high-value materials such as carbon-fiber composites, there may be questions of capability to retain physical properties consistent with re-use applications.<br><br>Statutory mandates in a global economy and environmental considerations also dictate a need to recover or make usable many non-metallic materials that are not presently recycled. Development of viable strategies for control of materials of concern is also critical to enhancing recyclability | Long-term goal (5-10+ years)<br><br>Remove any recycling barriers, real or perceived, to the use of advanced lightweighting materials or systems in future vehicles.<br>Enable the optimum recycling of automotive materials, obviating the need for legislative mandates.<br><br>Intermediate goals (3-5 yrs.)<br><br>A. Develop and demonstrate recycling process concepts for advanced materials (e.g. PMCs, aluminum, metal matrix composites.)<br><br>B. Demonstrate technical and economic feasibility of processes for materials recovery from ELV and shredder residue.<br><br>C. Facilitate transfer of technology to industrial practice.<br><br>D. Benchmark automotive materials recycling state-of-the-art and disseminate information to stakeholders. | Current Projects<br><br>Recycling Assessment and Planning<br>Baseline Technology Assessment<br>Post-shred Materials Recovery Technology Dev. & Demo.<br>Removal of PCBs and SOCs<br>Compatibilization of Recovered Polymers<br><br>Topics Requiring Further Research<br><br>Model Environmental Impact of Recycling<br>Develop WEB based Info System<br>Dismantling Process Improvements<br>Validation of Reman/Reuse Tech.<br>Advanced Vehicular System Recycle Technology (e.g. fuel cells, mg, metal matrix composites)<br>Rubber Recycling<br>Glass Recycling<br>Recycling Metallic Oxides<br>Recycling Mixed Polymers<br>Develop General Purpose Product from Recycled Materials |

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Figure 9. Recycling Strategy.

**Titanium** – Titanium is a relatively "new" metal. It was commercialized in the 1950s, primarily to meet aerospace needs and specifications. However, because of its strength, low mass, and heat and corrosion resistance, titanium is the leading alternative for lightest weight automotive coil suspension springs, exhaust system components, high performance fasteners, moving engine components, and components in fuel cell powertrain systems. It is the only lighter weight metal that can replace stainless steel and heat-treated alloy steels in highly loaded components.

Unfortunately, the current cost of titanium is too high to allow widespread automotive use. The research plan will focus on approaches that can reduce the raw material cost of titanium and titanium alloys. If successful, research on processing and manufacturing techniques to achieve cost parity in automotive applications will be pursued.

FreedomCAR Fuel Partnership **Materials**

Titanium

| Strategic Framework | Research Objectives | Current Projects and Perceived Needs |
|---|---|---|
| Titanium developed to replace alloy steels and stainless steel parts can achieve a mass reduction of 40-55%. Today's relative cost per part vs. steel is 1.5-10X.<br><br>Titanium is most often used in coil suspension springs, exhaust system components, moving engine components, and has potential applications in fuel cell powertrain systems.<br><br>Primary cost drivers are selection of the raw material ore, and the extraction method and reduction technology utilized.<br><br>Other cost drivers include the methods used for primary processing, secondary processing and finish processes | Long-term goal (5-10+ years)<br>Use titanium in specific components and structures to achieve 55% weight reduction with cost parity to competing materials<br>Intermediate goals (3-5 yrs.)<br>Use titanium in specific applications to create components and structures with 40% weight reduction and a relative cost of $2 per kg. of weight saved<br>•Develop and validate low cost Ti extraction and conversion technologies<br>•Develop low-cost technologies for melting and processing Ti into mill products<br>•Improve technologies for component manufacturing, including forming and machining<br>•Develop low-cost powder metallurgy processing techniques for net-shape manufacturing<br>•Develop new Ti alloys specific to automotive and fuel cell powertrain applications | Current Projects<br>•Low-Cost Powder for Feedstock (PNNL/ITP/Dupont)<br>•PM Technology for Particle Reinforced Ti (AMD 310)<br>Topics Requiring Further Research<br>•Demonstrate suitability of ilmenite feed materials for lower cost Ti reduction<br>•Demonstrate direct Ti alloy powder production technologies<br>•Evaluate effects of impurities on Ti and Ti alloy properties<br>•Develop melt-to-wrought processing technologies to reduce mill product cost<br>•Demonstrate PM processing of Ti and Ti alloy powders for net-shape components<br>•Develop low-cost forming and machining technologies for automotive components<br>•Demonstrate processing of reinforced Ti materials for automotive applications |

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Figure 10. Titanium Strategy.