1. INTRODUCTION

Automotive Lightweighting Materials R&D

As a major component of the U.S. Department of Energy's (DOE's) FreedomCAR and Vehicle Technolgies (FCVT) Program, Lightweighting Materials (LM) focuses on the development and validation of advanced materials and manufacturing technologies to significantly reduce automotive passenger-vehicle body and chassis weight without compromising other attributes such as safety, performance, recyclability, and cost.

Increased fuel economy is the most obvious effect of lighweighting. This term is used instead of "lightweight" so as not to imply just the use of lower-density materials. Steel, for instance, is not a low-density material, but by increasing its strength, less can be used for net weight reduction. It has been estimated that with every 10% drop in weight, the fuel economy increases 6–8% (with mass compounding and everything else the same). Mass compounding means that, in addition to the fuel economy increase due to the direct loss of weight by the given component or structure, other mass may be shed elsewhere in other vehicle components or structures such as the powertrain, the suspension and the braking.

In addition, lightweighting offsets the increased weight of features (e.g., audio, video and navigation systems), vehicle upsizing and performance (e.g., acceleration, safety, exhaust-gas pollution abatement) demanded by the customer or mandated by regulations. This has been the primary use of lightweighting in the recent past. In the future, lighweighting will be needed to offset the added weight and cost per unit of power of hybrid and fuel-cell powertrains.

The specific goals of LM are to develop material and manufacturing technologies by 2010 that, if implemented in high volume, could cost-effectively reduce the weight of passenger-vehicle body and chassis systems by 50% with safety, performance, and recyclability comparable to 2002 vehicles.

LM is pursuing five areas of research: cost reduction, manufacturability, design data and test methodologies, joining, and recycling and repair. The current long-range plan for activities in these areas is found at www.eere.energy.gov. Because the single greatest barrier to the use of lightweight materials is cost, priority is given to activities aimed at reducing costs through development of new materials, forming technologies, and manufacturing processes. Priority lightweighting materials include advanced high-strength steels (AHSSs), aluminum (Al), magnesium (Mg), titanium (Ti), and composites including metal-matrix materials and glass-, natural-, and carbon-fiber-reinforced thermosets and thermoplastics. The inclusion of AHSSs is an example, explaining the term "lightweighting," as opposed to "lightweight," in order not to imply focus on only lower density materials.

Collaboration and Cooperation

LM coordinates, cooperates and even collaborates extensively to identify, select and conduct its research and development (R&D) activities with others. The primary interfaces have been and still are with entities of Chrysler, Ford, and General Motors, namely, the FreedomCAR Materials

Technical Team (MTT), the Automotive Composites Consortium (ACC), the United States Automotive Materials Partnership (USAMP) and the Vehicle Recycling Partnership (VRP). These are the main means for determining critical needs, identifying technical barriers, prioritizing, assessing and selecting projects. Other important U.S. partners include the Auto/Steel Partnership (A/SP) of the American Iron and Steel Institute (AISI), the Plastics Division (formerly the American Plastics Council - APC) of the American Chemistry Council (ACC-PD), the American Foundry Society (AFS) and the North American Die Casting Association (NADCA). LM closely coordinates some of its R&D activities with those of Natural Resources Canada's (NRCan's) CANMET Materials Technology Laboratory due to common interests in automotive lightweighting in North America. Contacts with similar efforts in other countries are maintained. A major thrust in magnesium was initiated in fiscal year (FY) 2007 with CANMET and the China Magnesium Center of the Chinese Ministry of Science and Technology (MOST); see 6.A-C. Six projects at six universities are jointly funded with the U.S. National Science Foundation (NSF); see 8.L. Eight new projects, also jointly funded with the NSF and the A/SP, in the AHSS area were started in FY 2007; see 5.A. Another project at a university (see 8.I) is jointly funded with DOE's Office of Science. Sixteen projects (see 2.A, 3.E, 4.B and E, 5.M, 6.G-K, 8.H and M, 9.E, and 12.C and E) at the Mississippi State University (MSST), funded under a Congressional mandate, are coordinated with the mainstream LM activities. Five projects (6.D and E, 8.D, 10.C and 11.F and G) are funded under the DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) program.

Research areas and responsible organizations

Coordinated area	Organization
Fabrication of Mg	NRCan
Recycling and reuse of automotive parts and materials	Vehicle Recycling Partnership, Plastics Division of the American Chemistry Council (ACC-PD)
Fabrication of steel	American Iron and Steel Institute, the Auto/Steel Partnership
Fundamental materials and manufacturing research	National Science Foundation (NSF)
Production and fabrication of composites	ACC-PD

Projects Development and Selection

In cooperation with the USAMP and the MTT, a procedure has been established to help facilitate the development of projects. The LM has only rarely done open solicitations of projects. Most projects are usually developed by informal contacts with original equipment manufacturers (OEM) and/or national lab researchers and are brought forth for consideration, assessed and selected on the bases of recommendations of either the USAMP or the MTT. The LM, however, retains final say as to what is funded. This flexibility allows the LM to select the most appropriate partners to perform critical tasks that have optimal chances of migrating to OEMs or suppliers as application-engineering projects and eventually being implemented in production vehicles.

Once selected, R&D projects are pursued through a variety of funding mechanisms, including cooperative research and development agreements (CRADAs), cooperative agreements (CAs), university grants, R&D subcontracts, and directed research. Those developed through the USAMP CA are usually cost-shared equally (dollar-for-dollar) with the LM funds by the USAMP or other non-Federal sources, either in cash or in-kind. No LM funds are paid to the USAMP. Those projects developed through the MTT are usually performed at national laboratories and universities and not cost-shared.

Laboratories currently involved include Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories (SNL). ANL oversees the LM's recycling efforts (see 11A-E) and ORNL provides overall technical support and coordination, including for the CA with USAMP. The National Energy Technology Laboratory (NETL) provides external projects management including the CA with the USAMP and the NSF jointly-funded projects. ORNL and NETL monitor the MSST projects.

R&D projects are assigned to one of three phases as depicted in the figure and defined below: concept feasibility, technical feasibility, and demonstrated feasibility. Projects are guided to meet the requirements of each phase before they move on to the next phase. Not all projects must go through these phases under LM funding; some may enter the technical or demonstrated feasibility stages from efforts funded elsewhere.

Typical phases/stages of projects

Concept Feasibility: Concept-feasibility projects focus on a specific idea to address a need or to create something new. Projects are usually exploratory and small in monetary requirements and time, typically less than $200,000 total over 1–2 years, to provide a yes/no answer to the value of the idea. All projects are required to have a detailed research plan, budget, and timing. They can be ended before proceeding to technical feasibility if there is a lack of technical progress or if the preliminary business case turns out to be unfavorable. The SBIR-STTR Phase I projects are of this nature as well.

Technical Feasibility: Technical-feasibility projects typically continue R&D for ideas with proven concept-feasibility merit or potential. These projects should identify the key barriers to implementing the technology and focus on overcoming them. Technical-feasibility projects should have well-defined, industrial OEM and/or supplier participation and pull. They are usually larger and longer term than the concept feasibility projects with typical investment in the $1M to $2M (or more) range and length of 2–3 years (or more). Technical-feasibility projects can be ended before proceeding to demonstrated feasibility if there is a failure to overcome the key barriers to implementation or if the cost or business case does not develop as favorably as initially assessed. SBIR-STTR Phase II projects fit this paradigm.

Demonstrated Feasibility: Technology projects that need larger-scale validation may become demonstrated-feasibility projects. Not all technical-feasibility projects will need a demonstration or validation phase. These projects are few in number, much larger in scale, and may involve component or system fabrication and tests. Support and leverage from the industrial OEMs and/or suppliers is a key requirement.

FY 2007 Accomplishments

The High-Integrity Magnesium Automotive Castings (HI-MAC) project (see 3.D) is developing the metal-casting-process technologies necessary to cost-effectively manufacture high-integrity, cast Mg automotive-chassis components exhibiting high ductility and strength, low porosity, and which are free of objectionable oxides and inclusions. This project is developing the capability to cast Mg structural components based on existing Al low-pressure permanent-mold and squeeze casting processes. During this fiscal year, Mg control arms were produced from two of the Mg casting processes and will be provided for static and vehicle testing. The low-pressure die-casting machine and the Mg control arm produced therein are shown in Figures 1 and 2, respectively.

In addition, two new and emerging casting processes, ablation and T Mag, are also being investigated for potential use in casting structural Mg components. The use of controlled, molten-metal transfer and filling by an electromagnetic pump is being implemented to eliminate many of the production and environmental issues associated with the standard cover gas over Mg melts and yield higher-quality castings. Success in this project will result in increased production of Mg components requiring geometries and properties not possible with conventional high-pressure die-casting process limitations.

Figure 1. CMI Equipment and Engineering low-pressure casting cell.

Figure 2. Low-pressure, permanent-mold cast Mg control arm.

In the High-Volume Processing of Composites project (ACC 115, see 8.F), a measurement system was developed to objectively quantify the severity of bondline read-through (BLRT) in a way that correlates to visual assessment. BLRT is a visual defect that can occur where adhesive is used to bond a reinforcement to a Class “A” exterior panel and has been a deterrent to using composites because the “solution” is often to increase gage thus thwarting achievement of the theoretical weight savings available from carbon-fiber sheet-molding compound (SMC).

The Recycling End-of-Life Vehicles (ELVs) thrust (see 8.A-E) made significant progress during FY2007. The importance is that recovery and reuse of polymers and materials from ELVs will increase materials supply options and decrease costs for automakers and decrease the carbon footprint of lightweighting materials over the product life-cycle. The thrust developed and demonstrated effective recovery of high-quality polyolefins (at greater than 90% yield) from shredder residue, developed process conditions for selective recovery of acrylonitrile-butadiene-styrene (ABS), polystyrene (PS) and polycarbonate (PC) from shredder residue, and confirmed the technical feasibility of converting ELV shredder residue to fuels and chemicals. Commercialization of some of these processes is expected in the near future.

This thrust is conducted by a team consisting of personnel from ANL, the VRP, and the ACC-PD under a CRADA. The team received the Society of Plastics Engineers (SPE), Environmental Division Global Plastics Environmental Conference (GPEC) award in 2007 for "Enabling Technologies and Processes" in recognition of the team's contribution to development of ELV recycling technology.

The Low-Cost Carbon Fiber from Renewable Resources project (see 7.A) demonstrated that solvent-extracted, purified hardwood lignin can be continuously melt-spun into fiber form. This is a significant milestone in the search for low-cost carbon fiber.

The USAMP nondestructive Evaluation (NDE) Steering Committee issued a report entitled "Strategic Plan for Nondestructive Evaluation Development in the North American Automotive Industry" calling for increased development and application of NDE tools in the automotive industry to reduce waste, save money and energy, and help accelerate the introduction of new materials, processes, and vehicle technologies. The report looks at the expanding role of NDE in automotive production; identifies emerging challenges and prescribes a path to greater NDE development. The document represents a consensus between researchers at the U.S. Department of Energy (DOE) and the domestic automotive industry in suggesting that greater NDE use would also advance energy and environmental goals while improving production efficiency and reducing waste.

The Magnesium Front End (MFE) thrust (see 6.A-C and 6.F), the projects at MSST and the eight under NSF Funding for the Development of 3rd Generation Advanced High Strength Steels (see 5.A) began in FY 2007. MFE is a joint Canadian, Chinese, and U.S. effort aimed at development of automotive Mg technologies and, as such, may be the first of its kind. Other new starts included Ultra-fine Grained Foils and Sheets by Large Strain Machining Processes (see 2.E), Self-healing Coating Systems for Corrosion Control of Magnesium Alloys (see 6.D), Ferrate Conversion Coating for Corrosion Protection of High-Temperature Diecast Magnesium Alloys (see 6.E), and Development of High-Speed Multispectral Imaging for Sorting Automotive Plastics (see 11.F); the latter three short-term, SBIR-STTR projects were one-year projects and were thus also completed in FY 2007.

Besides the three short-term, SBIR-STTR projects, other projects that were completed included the Die-face Engineering Project for Advanced Sheet Metal Forming (2.D), Electromagnetic Forming of Aluminum Sheet (2.D), Improved Automotive Suspension Components Cast with B206 Alloys (3.A), and Thermal-Drilling Application Development (11.D). Science-base sub-projects of the Magnesium Powertrain Cast Components (3.B) also were concluded.

Future Directions

The current emphases on carbon-fiber-reinforced polymer-matrix composites and Mg will continue, as they have the greatest weight-reduction potential and costs. However, there will be some efforts on AHSSs, Al, and Ti because these materials will contribute in niche roles to the overall FreedomCAR weight-reduction and cost-neutrality goals. Material-crosscutting work in general manufacturing, will continue in joining, nondestructive evaluation (NDE), and recycling. Though technical-feasibility (see above) projects will dominate as before, concept-feasibility and demonstrated-feasibility projects will also be pursued as will some university base-technology projects.