1. INTRODUCTION

Lightweighting Materials Research and Development

As a major component of the U.S. Department of Energy's (DOE's) Vehicle Technologies Program (VTP), Lightweighting Materials (LM) focuses on the development and validation of advanced materials and manufacturing technologies to significantly reduce road transportation vehicle weight without compromising other attributes such as safety, performance, recyclability, and cost.

Increased fuel economy is the most obvious effect of lightweighting.* 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 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, and 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, more lightweighting may be needed to offset the added weight and cost per unit of power of hybrid, electric, and fuel-cell power trains and to extend the ranges of vehicles using them.

The current 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 lightweighting 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 glass-, natural-, and carbon-reinforced thermoset and thermoplastic polymeric-matrix composites.

Coordination, Cooperation, and Collaboration

LM coordinates, cooperates, and even collaborates to identify, select, and conduct its research and development (R&D) activities with others (Table 1). The primary interfaces have been and still are with entities of Chrysler, Ford, and General Motors (GM), 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) of the American Chemistry Council (ACC-PD), the American Foundry Society, and the North American Die Casting Association. LM closely coordinates some of its R&D activities with those of Natural Resources Canada'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 Mg, initiated in fiscal year (FY) 2007,

*The term "lightweighting" is used here 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.

Table 1. Research areas and responsible organizations

Coordinated area	Organization
Fabrication of Mg	CANMET
Recycling and reuse of automotive parts and materials	VRP, ACC-PD
Fabrication of steel	A/SP
Fundamental materials and manufacturing research	NSF
Production and fabrication of composites	ACC-PD

is in collaboration with CANMET and the China Magnesium Center of the Chinese Ministry of Science and Technology (see reports 6.A–6.C). Fourteen projects at universities are jointly funded with the U.S. National Science Foundation (NSF) (see reports 5.L–5.T and 8.K–8.O). Other universities participate in several other projects (see especially reports 2.A, 4.C, 6.G, and 8.I). Projects 2.A, 3.E, 4.B and 4.D, 6.F, 6.H and 6.I, 6.K–6.M, 8.G and 8.P, 9.F, and 12.C at the Mississippi State University (MSST), funded under a congressional mandate, are coordinated with the mainstream LM activities. Three projects (6.D, 10.B, and 11.E) are funded under the DOE Small Business Innovation Research and Small Business Technology Transfer (SBIR-STTR) programs.

Projects Development and Selection

In cooperation with USAMP and MTT, a procedure has been established to help facilitate the development of projects. LM has only rarely done open solicitations of projects. Projects are typically developed through informal contacts with original equipment manufacturers (OEMs) and/or national laboratory researchers and are brought forth for consideration, assessed, and selected on the bases of recommendations from either USAMP or MTT. DOE, however, retains final say as to what is funded. This flexibility allows 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 a CA with USAMP are cost-shared equally (dollar-for-dollar) with the LM funds by USAMP or other non-federal sources, either in cash or (mostly) in-kind. Those projects developed through MTT are usually performed at national laboratories and universities and not cost-shared.

Laboratories currently involved include Argonne National Laboratory, Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), and Sandia National Laboratories. The National Energy Technology Laboratory provides external projects management including the CA with USAMP, the projects jointly funded with NSF, and half of the MSST projects; ORNL oversees the other MSST projects.

Research and development projects are assigned to one of three phases as depicted in Figure 1 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.

Figure 1. 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.

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 lengths 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, are 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 2008 Accomplishments

The first design iteration of the Mg front end and technical cost modeling for the unibody steel front end (baseline) were completed by GM, Ford, Chrysler, Cosma, and Camanoe (see report 6.B). Gaps with respect to crash performance and meeting mass-reduction targets were identified. These are the first milestones in the joint effort between the United States, Canada, and China on developing and validating the front end, thereby demonstrating cost-effective weight reductions of 50% or more.

Selection of the material and process system and preliminary design for a structural-composite underbody were completed by the ACC, one of the formal consortia of the United States Council for Automotive Research (see report 8.A). This is an initial milestone in a roughly 5-year effort aimed at developing and validating technology for cost-effective weight reductions of 30% or more in a large, monolithic, safety-critical component.

ORNL established a partnership with FISIPE, S.A. in Lisbon, Portugal for producing commodity textile polyacrylonitrile (PAN) fiber precursor for lower-cost carbon fiber suitable for automotive body and chassis applications (see report 7.E). ORNL and FISIPE evaluated multiple PAN compositions and down-selected the most promising formulation. FISIPE selected a chemical pretreatment process for in-line modification of the precursor during the wet-spinning stage of processing, and ORNL established the stabilization, oxidation, and carbonization time-temperature-tension profiles for conversion of the precursor into carbon fiber. ORNL processed multiple 26,600 filament tows into carbon fiber using the ORNL carbon-fiber pilot line, exceeding program strength and modulus requirements. This is a step toward lower-cost carbon-fiber composites which are capable of effecting body and chassis weight reductions of 50% or more.

The A/SP fabricated and tested ten Phase-1 (materials substitutions) prototypes of a rear chassis structure using AHSSs and addressed the technology gaps related to fabricating AHSS structures (see report 5.H). They developed a methodology to determine the fatigue resistance of a chassis structure by virtual testing and prepared a Phase-2 design (complete redesign) which reduced the mass by 27% through use of AHSS, new architectures, and manufacturing innovations. Corrosion tests were passed successfully with coated substrates.

PNNL, ORNL, the University of Illinois at Urbana-Champaign, and Moldflow Corporation developed, validated, and implemented a new fiber-orientation model for long-fiber thermoplastic composites (see report 8.J). The model successfully predicted fiber-orientation tensor components for a glass-polypropylene ISO-plaque. This is part of a larger effort involving the above participants, the ACC-PD, and six other U.S. universities jointly funded by LM and NSF. This larger effort is aimed at improving the ability to predict the properties of fiber-reinforced composites.

A blue-ribbon panel of the National Materials Advisory Board of the National Research Council completed an 18-month study, partially supported by LM, of Integrated Computational Materials Engineering, the use of modern computational methods for the processing-structure-properties-relationships in materials. The work mentioned in the immediately preceding paragraph is an example. The study recognized that the materials field lags other engineering fields in the use of computerized modeling and made recommendations to overcome deficiencies. The study report is available at www.nap.edu.

Newly Started and Ended Projects

New starts in FY 2008 included Pulse Pressure Forming of Lightweight Materials (2.D), Formability of Continuous Cast Magnesium Sheet (2.F), Development of High-Strength Superplastic Aluminum Sheet (2.G), Multi-Material Metallurgical Bond Joining to Steel (3.F), Fundamental Study of the Relationship of Austenite-Ferrite Transformation (5.K), High-Strain-Rate Characterization of Magnesium Alloys (6.E), High Throughput Isotopic Diffusion Databases for Integrated Computational Materials Engineering (6.J), Precursor and Fiber Evaluation (7.D), Commercialization of Textile and Lignin Precursors (7.E), Composite Underbody Attachment (8.B), Evaluation of Composite Natural Fiber/Resin Compatibility (8.H), Friction Stir and Ultrasonic Joining of Magnesium to Steel (9.D), Friction Bit Joining (9.E), Online Nondestructive Weld Quality Monitor and Control with Infrared Thermography (10.C), Enhanced Resonance Inspection for Light Metal Castings (10.D), and Global Quality Assessment of Joining Technology for Automotive Body-in-White (10.E).

Uncharacteristically, no projects ended in FY 2008.

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 weight-reduction and cost-neutrality goals. Material-crosscutting work in general manufacturing will continue in joining, nondestructive evaluation, 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 and national laboratory base-technology projects.